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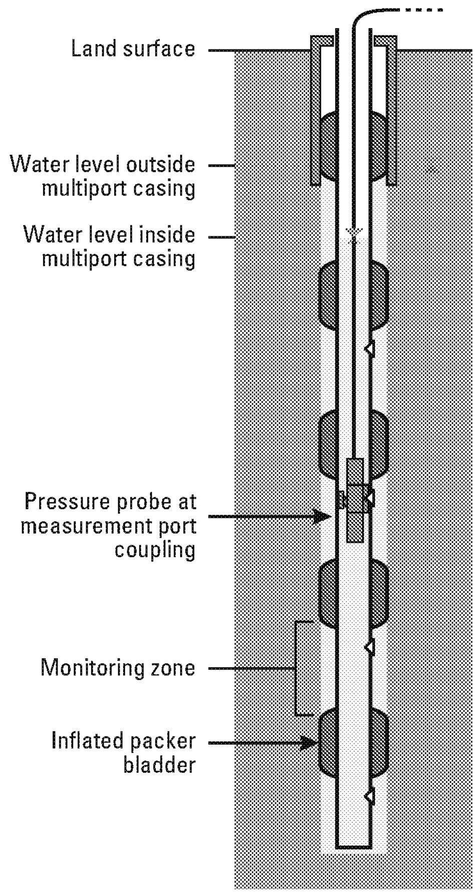
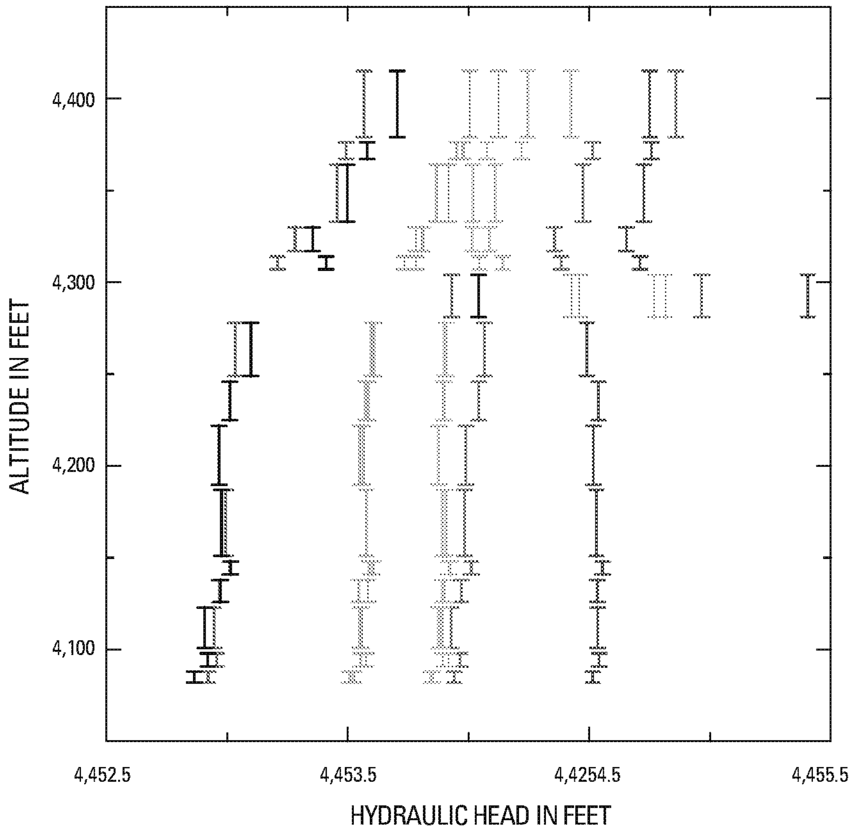
Prepared in cooperation with the U.S. Department of Energy

Multilevel Groundwater Monitoring of Hydraulic Head and Temperature in the Eastern Snake River Plain Aquifer, Idaho National Laboratory, Idaho, 2007–08





Scientific Investigations Report 2010–5253

U.S. Department of the Interior
U.S. Geological Survey

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Cover: Cross-section showing the components of a multi-packer borehole completion (left) and the hydraulic head profiles at the USGS 134 borehole corresponding to the 2007–08 measurement events (right).

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By Jason C. Fisher and Brian V. Twining

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U.S. Department of the Interior
KEN SALAZAR, Secretary

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Conversion Factors, Datums, and Abbreviations and Acronyms

Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Pressure	
pound per square inch (psi)	6.895	kilopascal (kPa)
	Density	
pound per cubic foot (lb ft^{-3})	16.02	kilogram per cubic meter (kg m^{-3})
	Hydraulic conductivity	
foot per day (ft d^{-1})	0.3048	meter per day (m d^{-1})
	Hydraulic gradient	
foot per mile (ft mi^{-1})	0.1894	meter per kilometer (m km^{-1})
	Transmissivity*	
foot squared per day (ft^2 d^{-1})	0.09290	meter squared per day (m^2 d^{-1})

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8×°C)+32.$$

*Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [(ft^3 d^{-1})ft^{-2}]ft. In this report, the mathematically reduced form, foot squared per day (ft^2 d^{-1}), is used for convenience.

Datums

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

Altitude and hydraulic head, as used in this report, refers to distance above the vertical datum.

Conversion Factors, Datums, and Abbreviations and Acronyms—Continued

Abbreviations and Acronyms

Abbreviation or acronym	Definition
ATR	Advanced Test Reactor Complex
bls	below land surface
CFA	Central Facilities Area
DGPS	Differential Global Positioning System
DOE	U.S. Department of Energy
ESRP	eastern Snake River Plain
head	hydraulic head
INL	Idaho National Laboratory
INTEC	Idaho Nuclear Technology and Engineering Center
MFC	Materials and Fuels Complex
MLMS	Multilevel Monitoring System
NRF	Naval Reactors Facility
PBF	Power Burst Facility
PCC	Pearson correlation coefficient
RWMC	Radioactive Waste Management Complex
TAN	Test Area North
USGS	U.S. Geological Survey

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Multilevel Groundwater Monitoring of Hydraulic Head and Temperature in the Eastern Snake River Plain Aquifer, Idaho National Laboratory, Idaho, 2007–08

By Jason C. Fisher and Brian V. Twining

Abstract

During 2007 and 2008, the U.S. Geological Survey, in cooperation with the U.S. Department of Energy, collected quarterly depth-discrete measurements of fluid pressure and temperature in six boreholes located in the eastern Snake River Plain aquifer of Idaho. Each borehole was instrumented with a multilevel monitoring system consisting of a series of valved measurement ports, packer bladders, casing segments, and couplers. Hydraulic heads (head) and water temperatures in boreholes were monitored at 86 hydraulically-isolated depth intervals located 448.0 to 1,377.6 feet below land surface. The calculation of head is most sensitive to fluid pressure and the altitude of the pressure transducer at each port coupling; it is least sensitive to barometric pressure and water temperature. An analysis of errors associated with the head calculation determined the accuracy of an individual head measurement at ±2.3 feet. Many of the sources of measurement error are diminished when considering the differences between two closely-spaced readings of head; therefore, a ±0.1 foot measurement accuracy was assumed for vertical head differences (and gradients) calculated between adjacent monitoring zones.

Vertical head and temperature profiles were unique to each borehole, and were characteristic of the heterogeneity and anisotropy of the eastern Snake River Plain aquifer. The vertical hydraulic gradients in each borehole remained relatively constant over time with minimum Pearson correlation coefficients between head profiles ranging from 0.72 at borehole USGS 103 to 1.00 at boreholes USGS 133 and MIDDLE 2051. Major inflections in the head profiles almost always coincided with low permeability sediment layers. The presence of a sediment layer, however, was insufficient for identifying the location of a major head change in a borehole. The vertical hydraulic gradients were defined for the major inflections in the head profiles and were as much as 2.2 feet per foot. Head gradients generally were downward in boreholes USGS 133, 134, and MIDDLE 2050A, zero in boreholes USGS 103 and 132, and exhibited a reversal in direction in borehole MIDDLE 2051. Water temperatures in all boreholes ranged from 10.2 to 16.3 degrees Celsius. Boreholes USGS 103 and 132 are in an area of concentrated volcanic vents and fissures, and measurements show water temperature decreasing with depth. All other measurements in boreholes show water temperature increasing with depth. A comparison among boreholes of the normalized mean head over time indicates a moderately positive correlation.

Introduction

The Idaho National Laboratory (INL) was established in 1949 by the U.S. Atomic Energy Commission, now the U.S. Department of Energy (DOE), for the development of peacetime atomic-energy applications, nuclear safety research, defense programs, and advanced energy concepts. The INL covers an area of about 890 mi^2 and overlies the west-central part of the eastern Snake River Plain (ESRP) in southeastern Idaho (fig. 1). A 50-plus year history of waste disposal at the INL has resulted in measurable concentrations of contaminants in the ESRP aquifer beneath the INL. Contaminants include several radiochemical, inorganic, and organic constituents (Mann and Beasley, 1994; Cecil and others, 1998; Bartholomay and others, 2000). The primary sources of contaminants are from facility wastewater disposal sites, such as lined evaporation ponds, unlined infiltration ponds and ditches, drain fields, and injection wells. Determining the long-term risks associated with contaminants currently in the aquifer or that might be in the aquifer in the future is difficult because of slow releases of residual contamination in the unsaturated zone or waste buried in shallow pits and trenches.

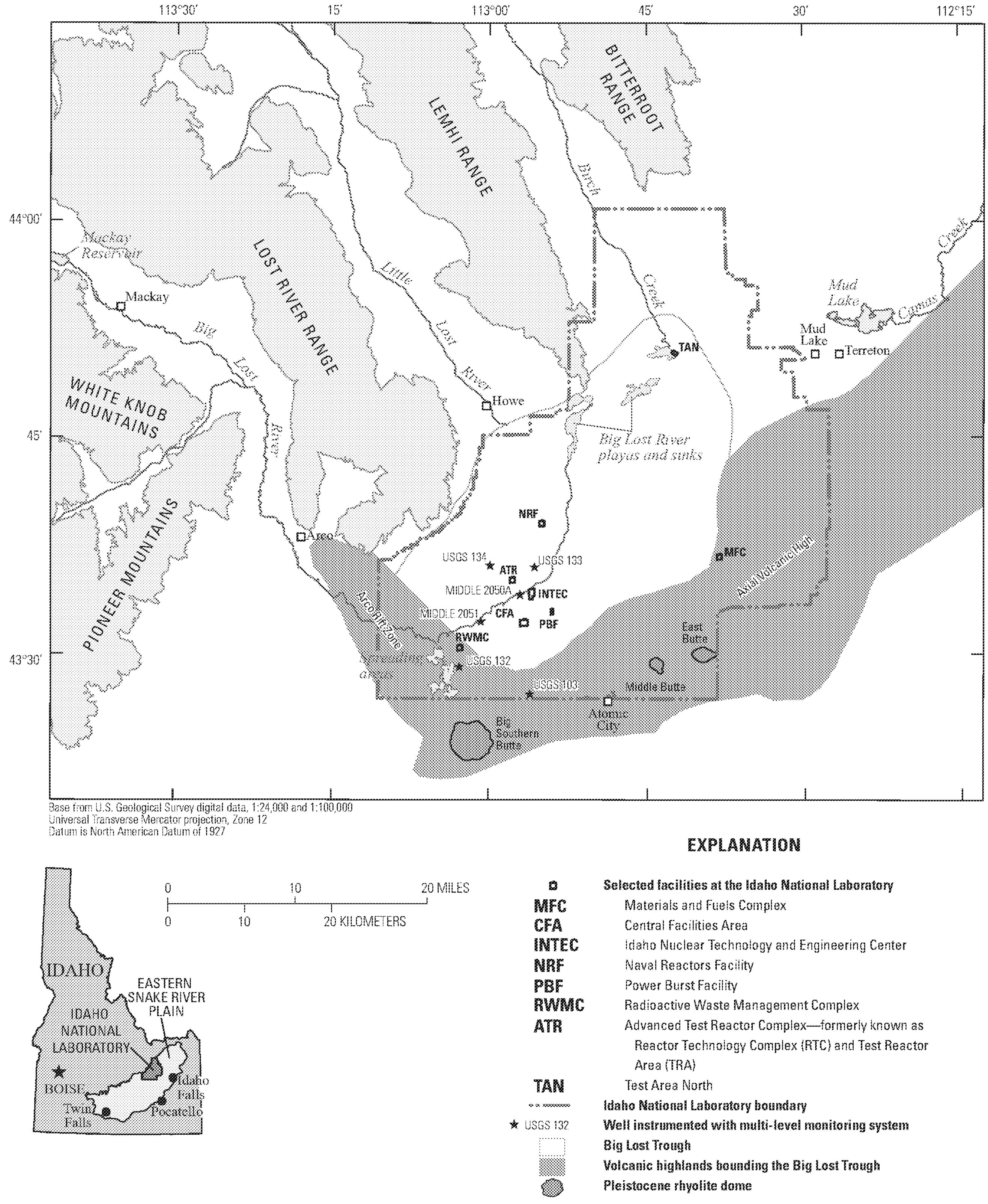

Figure 1. Location of selected facilities, multilevel monitoring wells, and volcanic highlands bounding the Big Lost Trough, Idaho National Laboratory and vicinity, Idaho.

Since 1949, the U.S. Geological Survey (USGS) has maintained a network of monitoring wells that record water levels and water quality in more than 200 boreholes with varying lengths of record. Most monitoring wells are open boreholes, and groundwater flow is unrestricted into or out of the open wells (fig. 2). The fractured basalts of the ESRP aquifer are well-suited for this type of completion; however, measurements collected from open-hole wells are independent of depth and represent, at best, a vertically-averaged composite value for the borehole that is heavily weighted by the highest hydraulic conductivity feature penetrated by the borehole.

Information on the vertical distribution of fluid pressures and chemistry is needed to better characterize, manage, and remediate contaminated groundwater in the ESRP aquifer. In 2005, the USGS, in collaboration with the DOE, began installing multilevel monitoring system (MLMS) boreholes (figs. 1 and 2) to provide quarterly, depth-discrete measurements of vertical hydraulic head (head) and temperature in cored boreholes drilled to depths ranging from 818 to 1,427 feet below land surface (ft bls). Depth-discrete water samples also were collected from these wells and were analyzed for chemical constituents (Bartholomay and Twining, 2010).

Purpose and Scope

Prior to the use of MLMSs, most wells in the USGS water-level monitoring network were completed to depths less than 200 ft into the aquifer and were used to record water-level observations. The data collected from these wells, however, has been insufficient to accurately describe the vertical movement of water and contaminants in the aquifer. The MLMS provides the necessary means to better characterize the areal extent and shape of contaminate plumes originating from the INL facilities. Completion depths for MLMS boreholes far exceed those of the average INL monitoring wells; therefore, any additional information pertaining to deeper flow and contaminant transport conditions will assist with ongoing efforts to characterize the full extent of downward plume migration in the aquifer.

This report describes multilevel groundwater monitoring in the ESRP aquifer, including the components of the MLMS, the installation of the MLMS, data collection methods, and quality assurance methods. The report summarizes and analyzes 2 years of quarterly head and water temperature data collected from six MLMS boreholes, and includes a description of the lithology and multilevel completion design for each borehole.

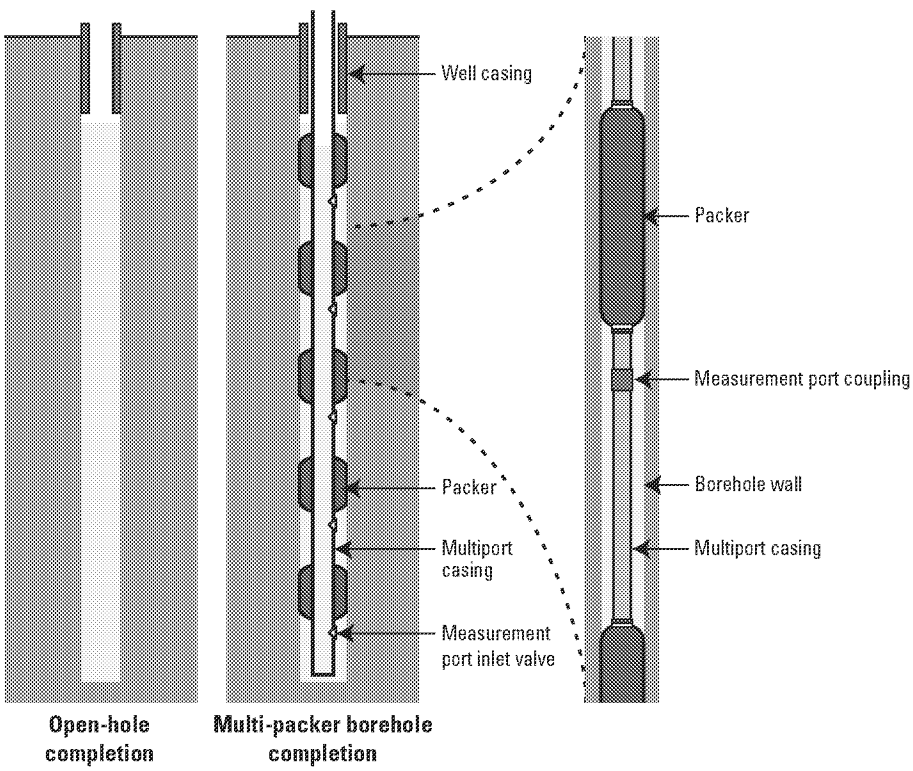

Figure 2. Open-hole and multi-packer borehole completions, eastern Snake River Plain aquifer, Idaho National Laboratory, Idaho, 2007–08.

Geohydrologic Setting

The study area is in the ESRP in Idaho, a relatively flat topographic depression, about 200 mi long and 50–70 mi wide (fig. 1). The INL is above the west-central part of the plain and all MLMSs are within INL boundaries. Streams tributary to the ESRP near the INL originate in mountain ranges north and west of the study site and include the Big Lost River, the Little Lost River, Birch Creek, and Camas Creek. The Big Lost River is the most significant surface-water feature in the study area. To prevent flooding of downstream facilities, a large percentage of the flow from the Big Lost River is diverted to a series of interconnected spreading basins near the southwest boundary of the INL.

The ESRP basin is bounded by faults on the northwest and by downwarping and faulting on the southeast, and has been filled with basaltic lava flows interbedded with terrestrial sediments. The basaltic rocks and sedimentary deposits combine to form the ESRP aquifer. Volcanic landforms of the ESRP include: (1) rhyolite domes (Kuntz and others, 1994), (2) sedimentary troughs (Gianniny and others, 1997), (3) vent corridors, and (4) volcanic highlands. The volcanic highlands are areas of focused volcanism resulting in higher concentrations of volcanic vents and fissures (Anderson and others, 1999, p. 13; Hughes and others, 1999, p. 145); the major sources of basaltic rocks on the plain. A typical basalt flow has vesicular zones and cooling fractures on the top and sides, with vesicle sheets, pipe vesicles, mega vesicles in the interior, and a diktytaxitic to massive core (fig. 3). The Big Lost River has been the main source of sediment since late Pliocene time, resulting in a depocenter known as the Big Lost Trough (fig. 1; Geslin and others, 2002). The Big Lost Trough contains significantly greater amounts of sediment than has been measured in boreholes in other parts of the INL (Anderson and others, 1999, fig. 9, table 2; Hughes and others, 2002; Welhan and others, 2007). Sediments penetrated by boreholes on the INL range from 0 to 313 ft thick and are thickest in the northwestern part of the INL (Anderson and others, 1996; Welhan and others, 2007).

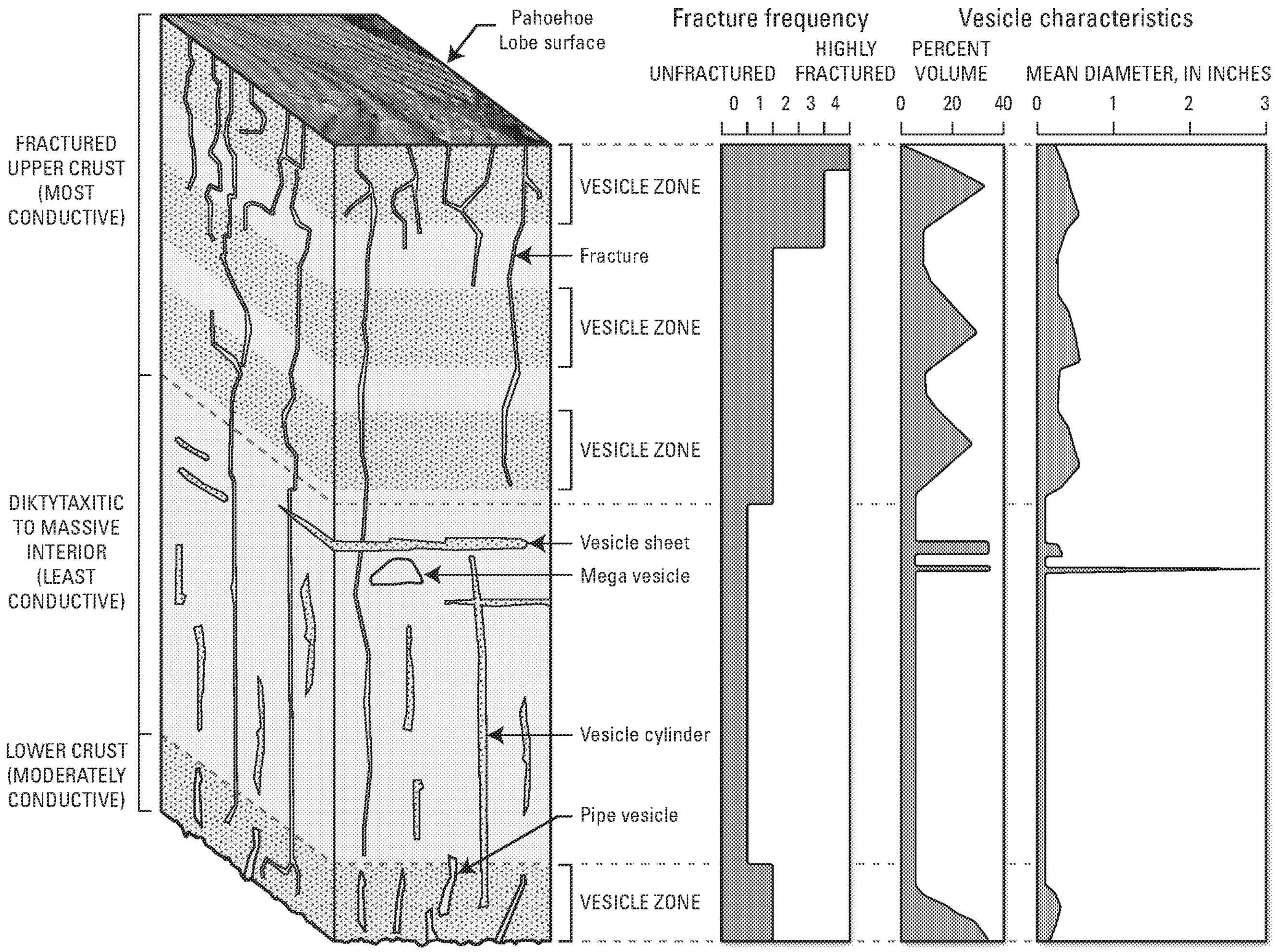

Figure 3. Typical olivine tholeiitic pahoehoe basalt flow. (Modified from Self and others, 1998, p. 90, fig. 3). The basalt flow is divided into three sections on the basis of vesicle characteristics and fracture frequency. Hydraulic conductivity is highest for the fractured upper crust, moderate for the lower crust, and lowest for the diktytaxitic to massive interior. Photograph of the pahoehoe lobe surface courtesy of Scott Hughes, Idaho State University, Pocatello, Idaho.

The ESRP aquifer is one of the most productive aquifers in the United States (U.S. Geological Survey, 1985, p. 193). The 2008 water table (Twining and others, 2010), represented in figure 4 as line contours of equal hydraulic head, shows a southwest regional flow direction in the aquifer that eventually discharges to springs along the Snake River downstream of Twin Falls, Idaho—about 100 mi southwest of the INL (fig. 1). Along the northwest mountain front, surface water and underflow enter the aquifer system from three tributary valleys, the Big Lost River, Little Lost River, and Birch Creek. Groundwater moves horizontally through basalt interflow zones and vertically through joints and interfingering edges of interflow zones. Infiltration of surface water, heavy pumpage, geologic conditions, and seasonal fluxes of recharge and discharge locally affect the movement of groundwater in the aquifer (Garabedian, 1986). Recharge primarily is from the infiltration of applied irrigation water, streamflow, precipitation, and underflow from the tributary valleys to the plain.

Across the INL, borehole water-table altitudes range from about 4,560 to 4,410 ft (fig. 4). Depth to the water table ranges from about 200 ft north of the INL to more than 900 ft in the southeast. Ackerman (1991, p. 30) and Bartholomay and others (1997, table 3) reported a range of transmissivities for basalt in the upper part of the aquifer of 1.1 to 760,000 $ft^2\ d^{-1}$. The hydraulic gradient at the INL ranges from 2 to 10 $ft\ mi^{-1}$, with an average of about 4 $ft\ mi^{-1}$ (Davis, 2008). Horizontal groundwater flow velocities ranging from 2 to 20 $ft\ d^{-1}$ have been calculated based on the movement of various constituents in different areas of the aquifer beneath the INL (Robertson and others, 1974; Mann and Beasley, 1994; Cecil and others, 2000; Busenberg and others, 2001). Localized tracer tests at the INL have shown vertical and horizontal transport rates as high as 60–150 $ft\ d^{-1}$ (Nimmo and others, 2002; Duke and others, 2007).

Previous Investigations

Several reports describing the geology and hydrology of the ESRP at the INL have been published; copies of these reports may be obtained from the USGS INL Project Office (http://id.water.usgs.gov/projects/INL/pubs.html) and the USGS Publications Warehouse (http://infotrek.er.usgs.gov/pubs/).

Multilevel groundwater monitoring at the INL was first documented by Whitmore and others (2007). The focus of their investigation was the drilling, completion, and monitoring of MLMSs at boreholes MIDDLE 2050A and MIDDLE 2051. Various studies have focused on the use of multilevel groundwater monitoring systems within fractured rock aquifer systems. An investigation on the use of multichannel tubing to monitor depth-discrete zones in a single borehole in unconsolidated sediment and bedrock was made by Einarson and Cherry (2002). The authors provide descriptions of the MLMS components, method of installation, head monitoring, well tests, and sampling techniques, as well as an analysis of vertical head and water chemistry data for several monitoring sites. The authors also examine vertical head and water chemistry data for several monitoring sites. The advantages of depth-discrete data to explain flow and contaminant transport in a heterogeneous groundwater system are discussed in Parker and others (2006). Their work gives specific details on the installation and setup of a MLMS and presents vertical head data within two rotosonic boreholes. An overview of multilevel monitoring in groundwater systems was provided by Einarson (2006) and includes a history of the technology and a comparison between different MLMSs, that is, the Westbay™ System, Solinst™ Waterloo System, Solinst™ Continuous Multichannel Tubing System, and Water FLUTe™ System. Cherry and others (2007) demonstrate the use of the Water FLUTe™ technology in a contaminated fractured rock aquifer. Meyer and others (2008) analyzed vertical heads in a layered fractured sedimentary rock and suggest that multilevel monitoring is essential for defining hydrogeologic units.

Methods

The methods used to collect depth-discrete measurements of hydraulic head and temperature are described in the following sections of this report: (1) *Multilevel Monitoring System*, which describes the components of the MLMS; (2) *Installation*, which summarizes the steps taken to install the MLMS within an open borehole; (3) *Profiling and Completions*, which describes the methods used to construct head and temperature profiles within a borehole; and (4) *Quality Assurance*, which describes the accuracy and precision of head and temperature measurements.

Multilevel Monitoring System

The multilevel groundwater monitoring technology used in this study is the Westbay™ System, manufactured by Schlumberger Water Services (2010) (accessed October 14, 2010, at http://www.swstechnology.com). This type of MLMS is composed of two parts: (1) a modular borehole completion system consisting of packers, measurement ports, and variable length sections of polyvinylchloride (PVC) casing (fig. 2) and (2) a portable sampling probe (MOSDAX™) and data acquisition system (MAGI™). The multi-packer borehole completion is designed to allow depth-discrete monitoring of hydraulic head and groundwater quality in a borehole. The MLMS uses a continuous string of water-tight casing that runs the entire length of a borehole. Monitoring zones in a borehole are separated by inflated packer bladders that maintain hydraulic isolation between zones. The modular construction and varying lengths of casing sections allow sampling ports and packer bladders to be placed at almost any desired depth in a borehole.

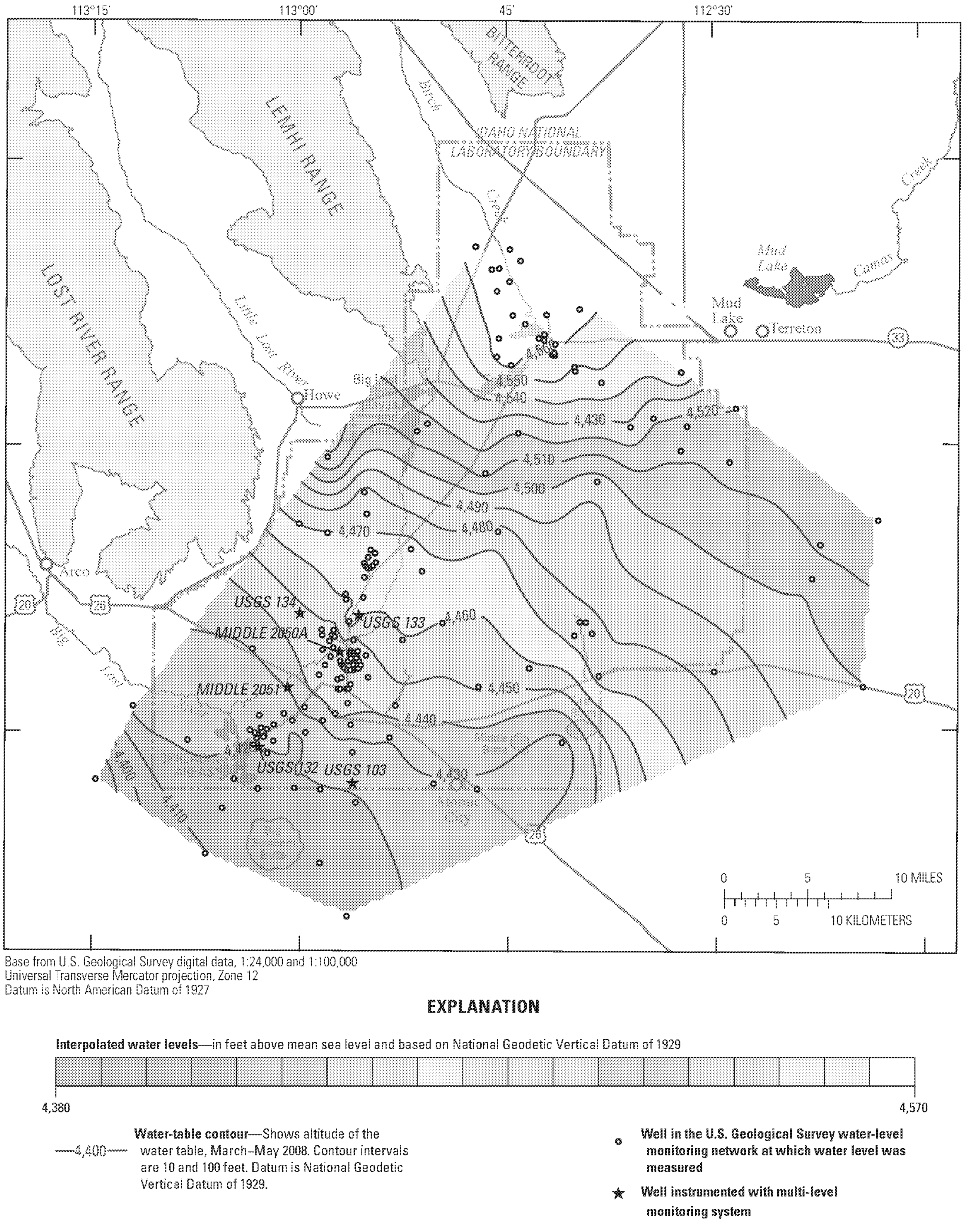

Figure 4. Water-table contours, March–May 2008, and monitoring wells, Idaho National Laboratory and vicinity, Idaho. (Modified from Twining and others, 2010, fig. 4).

Two versions of the Westbay™ System were used in this study: the MP55 and the MP38. Both MP systems use similar packers, ports, and casing segments; however, components of the MP38 system are smaller in diameter and are best suited for 3 to 4.5 in. boreholes, whereas, the MP55 system is designed for larger borehole diameters ranging from 4.75 to 6.25 in. The primary advantage of the MP55 system is that it permits the collection of larger sample volumes of about 2 liters; in comparison, the sample volume for the MP38 system is about 1 liter. Five of the six multiport boreholes are furnished with the MP55 system. The only MP38 system in use at the INL is at borehole USGS 134; a maximum size constraint on its borehole diameter prevented the installation of the larger MP55 system.

Several types of MLMSs were considered for this study, but only the Westbay™ System met the design criteria for boreholes in the ESRP aquifer at the INL. These criteria included a borehole diameter ranging from 4 to 6 in. and a water table depth and total aquifer thickness exceeding 600 and 1,000 ft, respectively.

Installation

The four phases of MLMS installation are (1) design, (2) layout, (3) component setting, and (4) packer inflation. In the design phase, the borehole core, geophysical data, and downhole video were examined to determine horizons of hydrologic interest and to identify suitable locations for packers and measurement ports. Photographs and descriptions of cored material were crosschecked with geophysical data to identify areas of competent and fractured basalt and sediment. In the MLMS design, competent rock zones were selected for packer seals, and fractured rock sections were targeted for discrete monitoring zones. The low permeability sediment zones were typically unsuitable for packer placement due to borehole wall instabilities, where borehole breakouts could potentially compromise the hydraulic seal of the packer. The final MLMS design was documented in an installation log. Detailed descriptions of core and lithologic profiles for USGS 132, USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051 were provided by Twining and others (2008) and North Wind, Inc. (2006). A combination of caliper, gamma-gamma density, natural gamma, and neutron geophysical logs were used to measure the borehole diameter, bulk density, location of sediment units, and volumetric water content. Gyro deviation surveys provided corrections for borehole deviations, the angular change in the drill hole from vertical. The geophysical data were collected using Century™ logging equipment and processed with WellCAD™, a composite log software package. Downhole video surveys were used to evaluate the condition of borehole walls and to identify problem areas (that is, loose rock and unstable sediment zones). These videos also were used to determine the placement of temporary guide tubes during the component setting phase of the MLMS installation.

After each MLMS was designed, the casing, valved measurement ports, packers, and couplers were laid out on pipe racks in the order of installation and inspected according to the component sequence documented in the installation log (fig. 5). Components were visually examined for defects, and then were measured to ensure that errors in component length were no more than 0.01 ft. This information was recorded in the installation log along with serial numbers for each measurement port and packer to facilitate assemblage later on. Additionally, components were kept clean and dry using plastic tarps and sleeves to prevent unnecessary damage to the equipment.

In the component setting phase of installation, the MLMS is assembled in the borehole. The stages of assembly are shown in figure 6. A 4.6 ft diameter guide tube, constructed from steel tubing and used to stabilize loose material along the borehole wall, was first lowered into the open borehole (fig. 6*A*). The multiport casing was then inserted into the guide tube and lowered to a depth that extended beyond the length of the guide tube (fig. 6*B*). During the assembly of the MLMS leak tests were run on each casing joint using a mini-packer system (fig. 7*A*) to force 200 psi of pressurized water across each joint; water pressurization was achieved using a portable hydraulic pump (fig. 7*B*). If a leak was discovered during a test, that section of multiport casing would be re-inspected and replaced, if necessary. While lowering the multiport casing, deionized water was added to the inside of its casing to counteract the effects of buoyancy resulting from groundwater displacement. When lowering was complete, the depth-to-water inside the casing was monitored over several hours to ensure hydraulic isolation within the multiport casing. Additional deionized water then was added so that the water level inside the casing was just below the water level in the borehole. The lower water level within the multiport casing provided a means of easily distinguishing between inside (casing) and outside (aquifer) water pressures. The measurement port inlet valves were then tested to ensure proper functionality and depth positioning.

The last steps in the component setting phase were inflation of the packer glands and removal of the guide tube. Packers were individually inflated using a hydraulic inflation tool that was lowered through the multiport casing to port depths corresponding to each packer gland. Water was then incrementally injected into the packer gland while fluid pressure was monitored to ensure proper inflation and seal against the borehole wall. Removal of the guide tube and inflation of the packers occurred in a stepwise manner. First, the uninflated packers located beneath the guide tube were inflated (fig. 6*C*). With the weight of the MLMS held by the inflated packers, the guide tube was then incrementally raised and the next set of uninflated packers was exposed to the borehole wall. The process was repeated until all packers were inflated and the guide tube was completely removed (fig. 6*D*). Lastly, measurement ports were again tested to ensure proper functionality.

Figure 5. Pre-assembly of the components during the layout phase of Multilevel Monitoring System installation, Idaho National Laboratory, Idaho, 2007–08.

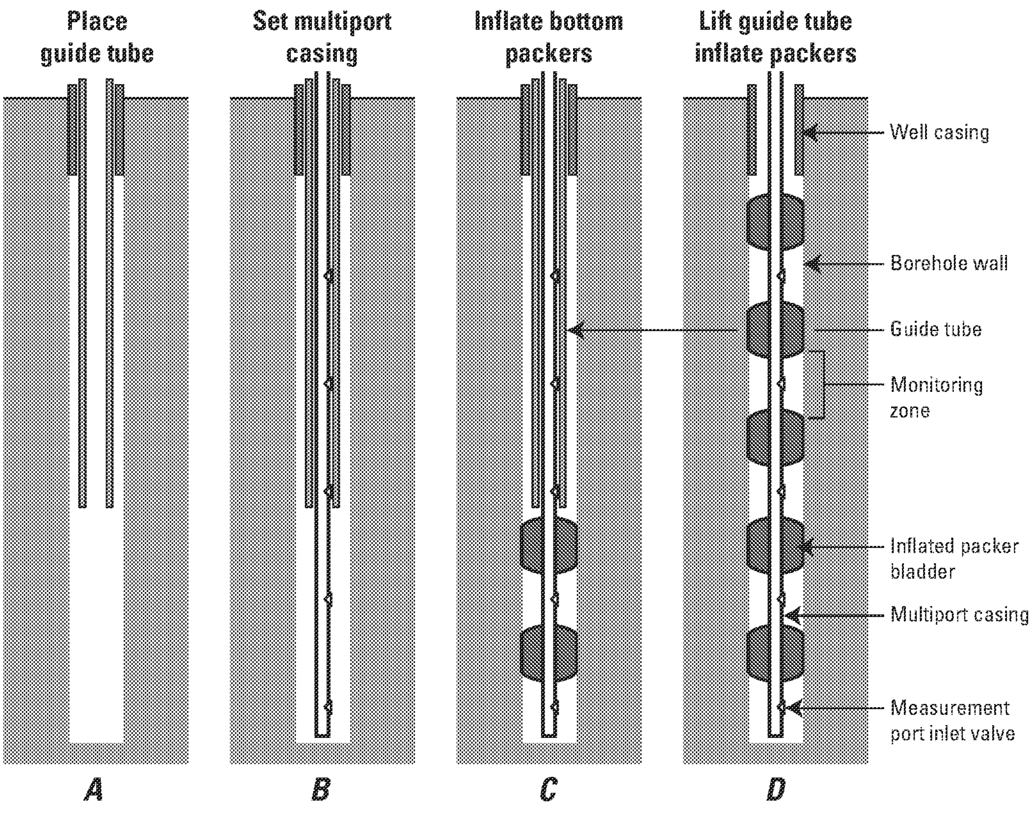

Figure 6. Stages of assembly for the component setting phase of the multilevel monitoring system installation, Idaho National Laboratory, Idaho. (*A*) The guide tube is first placed into the open borehole, (*B*) the multiport casing is set, (*C*) the bottom packer glands are inflated, and (*D*) the guide tube is removed with packer inflation.

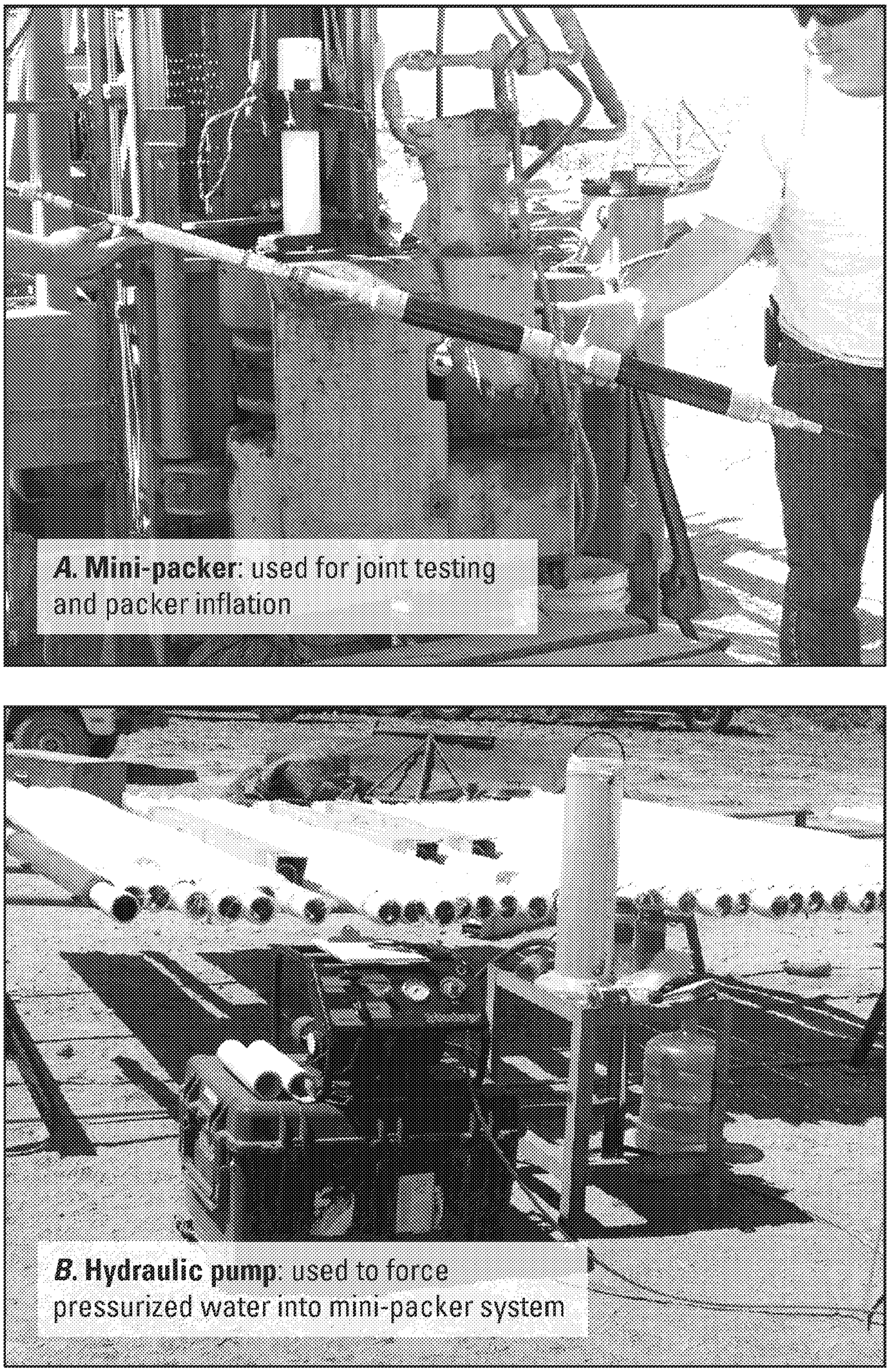

Figure 7. Testing a casing joint for leaks using (*A*) mini-packer system to force pressurized water across the joint and (*B*) hydraulic pump to pressurize water, Idaho National Laboratory, Idaho.

Profiling and Completions

An individual head or temperature profile represents a set of measurements collected over a relatively short period. The actual time required for each measurement period varied, and was dependent on the quantity and spacing of ports within a MLMS. Profile measurements in this study were less than 2 hours, a period considered instantaneous when contrasted to the slow response times of groundwater systems.

Fluid pressure and temperature measurements were made using a portable sampling probe, a wireline-operated probe that is lowered into the multiport casing from the land surface and positioned at a selected measurement port coupling (fig. 8). The positioned probe is then coupled with the measurement port inlet valve to allow monitoring of groundwater outside the multiport casing and within the monitoring zone; where groundwater in this zone is vertically isolated between upper and lower packers. Coupling the probe with the measurement port inlet valve is done by extending the backing shoe on the probe to create a hydraulic seal between the probe and the port and to open the port. Fluid pressure and temperature measurements are then transmitted to the land surface through the wireline communication cable, processed using a data acquisition system, and recorded on a datalogger. The hydraulic head at each measurement port assuming 100 percent barometric efficiency was expressed as

$$H = \Psi_2 + Z - D = \left(\frac{P_2 - P_{Atm}}{\gamma_w}\right) \times 144 + Z - D, \qquad (1)$$

where

H is the hydraulic head, in feet (ft);
Ψ_2 is the pressure head recorded outside the multiport casing, in ft;
Z is the altitude of a referenced land surface measurement point, in ft;
D is the depth to the pressure transducer sensor at the measurement port coupling, in feet below land surface (ft bls);
P_2 is the fluid pressure measured outside the multiport casing in pounds per square inch absolute (psia);
P_{Atm} is the atmospheric pressure measured at land surface, in psia;
γ_w is the specific weight of water, in pound per cubic foot (lb ft^{-3}).

Atmospheric pressure was monitored at the land surface using a hand-held barometric sensor. The specific weight of water was calculated as a function of temperature only (McCutcheon and others, 1993), assuming negligible salinity and gravitational differences between measurements, and expressed as

$$\gamma_w = 62.42796 \times \left\{1 - \left(\left[\frac{T + 288.9414}{508929.2 \times (T + 68.12963)}\right] \times (T - 3.9863)^2\right)\right\}, \qquad (2)$$

where

γ_w is in units of lb ft^{-3}; and
T is water temperature measured inside the multiport casing from the bridge of pressure transducer in degrees Celsius (°C).

The depth to the pressure transducer sensor at a port coupling was measured once (appendix A) and calculated as

$$D = \Psi_1 + L_1 = \left(\frac{P_1 - P_{Atm}}{\gamma_w}\right) \times 144 + L_1, \qquad (3)$$

where

D is the depth to the pressure transducer, in ft bls;
Ψ_1 is the pressure head recorded inside the multiport casing, in ft;
L_1 is the depth to water inside the multiport casing, in ft bls;
P_1 is the fluid pressure measured inside the multiport casing, in psia.

The depth to water inside the multiport casing (L_1) was measured using an electronic measuring tape and corrected for borehole deviation. Simultaneous measurements of P_1, P_{Atm}, and L_1 were made at each port coupling to account for (1) temporal changes in atmospheric conditions and (2) a depth to water that was dependent on the volume of water displaced by the wireline communication cable.

Multilevel completions included the location of measurement port valves, port couplings, packers, and monitoring zones in the borehole (where a monitoring zone describes the volumetric space between consecutive packers outside the multiport casing). The location of a multilevel component in a borehole is based on the measured depth to the pressure transducer at a port coupling (eq. 3) and its position within the MLMS installation log. For example, the length of a monitoring zone is defined as the distance between two consecutive packer seals and calculated by subtracting the depth at the bottom of the upper packer from the depth at the top of the lower packer, or

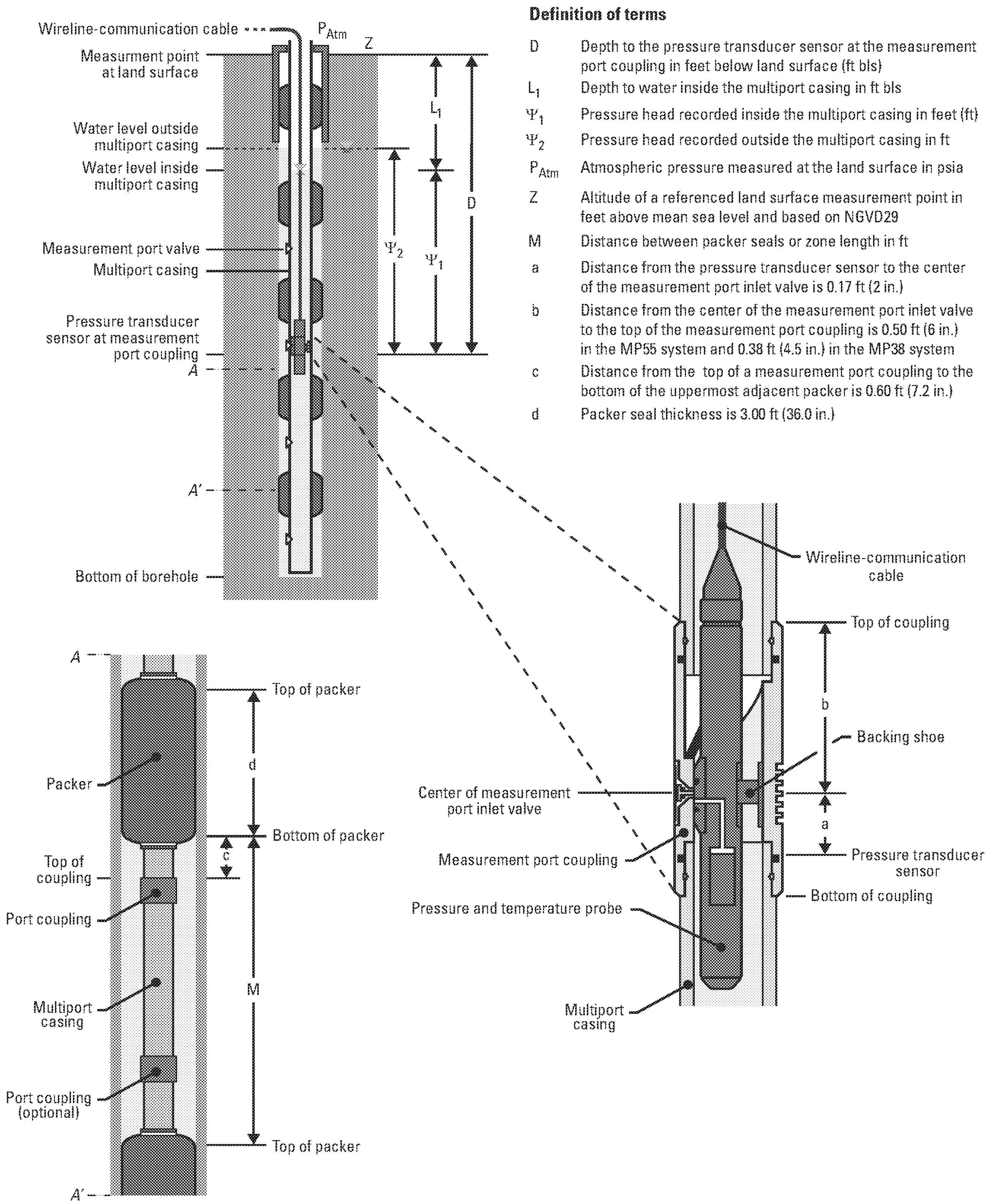

Figure 8. Terms used in the calculation of hydraulic head based on the portable probe position when coupled with a measurement port in the multilevel monitoring system. (Modified from Westbay™, written commun., 2009.)

$$
\begin{aligned}
M_z &= \left(D_{z-1} - a - b - c - d\right) - \left(D_z - a - b - c\right) \\
&= D_{z-1} - d - D_z,
\end{aligned} \tag{4}
$$

where

M_z is the distance between packer seals in monitoring zone z, in ft;

D_z is the depth to the pressure transducer sensor in the uppermost port coupling of zone z, in ft bls;

D_{z-1} is the depth to the pressure transducer sensor, in the uppermost port coupling of zone $z-1$, in ft bls, where z decreases with depth;

a is the distance between the pressure transducer sensor and the center of the measurement port inlet valve, in ft, 0.17 ft in both MP systems;

b is the distance between the center of the measurment port inlet valve and the top of the measurement port coupling, in ft, 0.50 ft in the MP55 system and 0.38 ft in the MP38 system;

c is the distance between the uppermost measurement port coupling and the bottom of the adjacent packer, in ft, 0.60 ft in both MP systems;

d is the thickness of the inflated packer seal, in ft, 3.00 ft in both MP systems.

Parameters a, b, c, and d were defined using nominal component lengths specified in the MLMS installation log (fig. 8); however, actual parameter lengths may vary because of component deformation in the multiport casing and port couplings that results from mechanical stretch and thermal expansion during MLMS installation, although destressing during packer inflation was used to reduce the total strain on the system. Measurement errors associated with component deformation were assumed negligible because nominal component lengths were relatively small when compared to the measured depth to a pressure transducer (D).

Standard procedures were adopted for collecting profile measurements. First, the sampling probe was lowered to the deepest measurement port in the MLMS. Next, the probe was coupled with the monitoring port and fluid pressure and temperature were monitored, where pressure was measured outside the multiport casing and temperature was measured from inside the probe. Final measurements of fluid pressure, atmospheric pressure, and water temperature were recorded on a field sheet (appendix B) after temperature readings stabilized with fluctuations less than 0.1 °C. The time for temperature stabilization varied and was dependent on the time required for the portable sampling probe to equilibrate to groundwater temperatures near the measurement port. The temperature sensor is embedded in the sampling probe to protect it from damage while traversing the borehole. Low rates of heat transfer between the groundwater and the sensor inside the probe resulted in temperature stabilization times of as much as 30 minutes. The longest period for temperature stabilization occurred at the first measurement port, where the temperature of the probe transitions between air temperatures at the ground-surface to groundwater temperature within the deepest port. After a fluid pressure and temperature measurement were recorded, the probe was decoupled from the port and raised to the next highest measurement port; the process was repeated until all ports have been monitored and final measurements recorded.

Custom computer programs were developed using the R programming language (R Development Core Team, 2010) to process and graph the head and temperature profiles in each borehole. An example of a head profile plotted and illustrating the effect of packer inflation on vertical head is shown in figure 9. The illustration shows head profiles in borehole USGS 133 at pre- and post-inflation of the packer bladders during the installation of the MLMS, where the time elapsed between profiles was about 28 hours. Head measurements pre- and post-inflation are provided in appendix C. In the pre-inflation profile, head is plotted with respect to the pressure transducer depth at a port coupling; whereas, in the post-inflation profile, head is plotted with respect to the entire monitoring zone. In theory, head is equivalent throughout a monitoring zone with flow dominated by the most transmissive feature penetrated by the borehole in this zone. Head values reported at monitoring zones containing a second measurement port reflect an average of the two head values. As expected, the pre-inflation profile (open borehole) shows almost hydrostatic conditions with less than 0.5 ft of vertical head change in the borehole; whereas, the head difference post-inflation (packer-sealed borehole) was 23 times greater than pre-inflation at 6.6 ft and indicated a downward vertical hydraulic gradient.

Quality Assurance

Standards for collecting groundwater levels and water-quality samples within a well are clearly documented (M.L. Jones, U.S. Geological Survey, written commun., 1988; U.S. Geological Survey, variously dated); however, standards for MLMSs have not yet been established. The following approach was used to quantify the accuracy and precision of MLMS head measurements reported in this study and the assurance of quality in the data.

Hydraulic head, as defined by equations 1 and 2, is dependent on five variables: (1) the water temperature outside the multiport casing measured indirectly by the temperature sensor inside the multiport casing and in the sampling probe; (2) the fluid pressure outside the multiport casing measured by the sampling probe; (3) the atmospheric or barometric pressure measured at the top of the multiport casing at the land surface; (4) the altitude of a reference point at the land

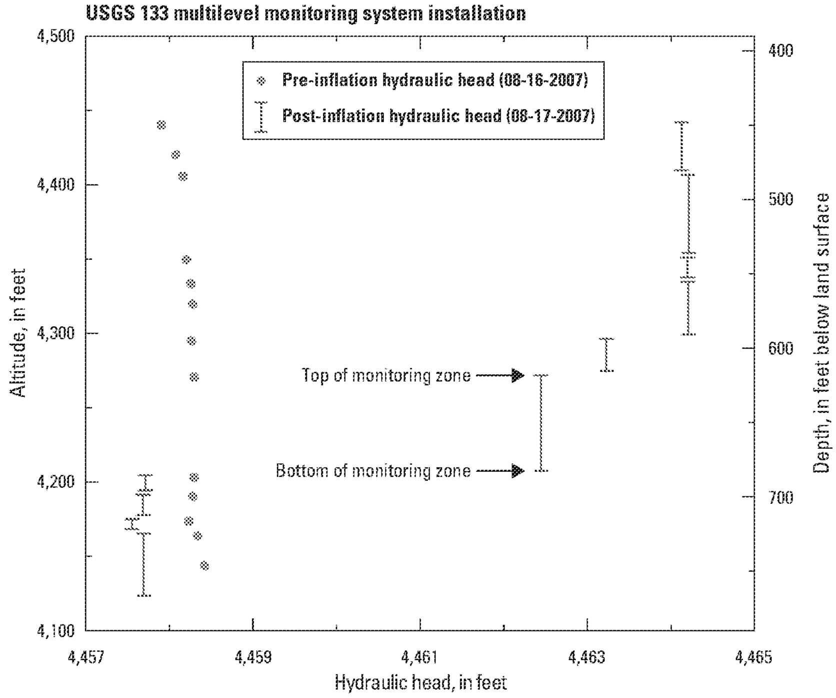

Figure 9. Vertical hydraulic head profiles showing pre- and post-inflation of the packer bladders at borehole USGS 133, Idaho National Laboratory, Idaho, August 16–17, 2007.

surface; and (5) the vertical depth, or distance between the land surface reference point and the pressure transducer sensor in a measurement port coupling.

The water temperature inside the multiport casing was measured at an assumed accuracy of ±0.1 °C because information regarding the accuracy of this sensor was unavailable by the manufacturer. The fluid pressure was measured at a specified accuracy of ±0.500 psi, or ±1.15 ft when converted to head at 13 °C. Calibration of the fluid pressure sensor was performed by the probe manufacturer on December 21, 2006, October 20, 2007, October 22, 2008, and November 7, 2009; results from these tests are shown in appendix D. Each test was run over a referenced pressure range of 15–500 psia, with probe temperature held constant at 10 and 20 °C. Accounting for the range of fluid pressures measured in the field, from 30 to 350 psia, the calibration tests gave a standard deviation for the measurement accuracy of ±0.118 psi (or ±0.27 ft at 13 °C), and indicates that fluid pressure error remained well below the sensors specified accuracy during the duration of the study. Calibration corrections were not applied to fluid pressure measurements because of the relatively high specified accuracy of the reference pressure sensor at ±0.100 psi (or ±0.23 ft at 13 °C).

Atmospheric pressure was measured with a GE™ Druck DPI 740 portable barometer at a specified accuracy of ±0.005 psi (or ±0.01 ft at 13 °C); calibration data was not available for this sensor. The altitude of the land surface reference point was measured by a professional land surveyor licensed in the State of Idaho using a Differential Global Positioning System (DGPS). Altitudes are reported using the NGVD 29 at a specified accuracy of ±0.01 ft. The calculated pressure transducer sensor depth is dependent on the pressure head and depth to water inside the multiport casing (eq. 3). Summing the relative uncertainties of fluid pressure (±1.15 ft at 13 °C), atmospheric pressure (±0.01 ft at 13 °C), and depth to water (±0.02 ft) gives a measurement error of ±1.18 ft for the pressure transducer depth.

Finally, the cumulative error for independent head readings is ±2.3 ft; a value determined by summing measurement accuracies for fluid pressure (±1.15 ft), atmospheric pressure (±0.01 ft), land surface altitude (±0.01 ft), and pressure transducer sensor depth (±1.18 ft). Note that many of the sources of measurement error are diminished when considering the differences between two closely-spaced readings of head; where head values are monitored using the same pressure probe, at similar depths, and at similar water densities. Under these conditions, vertical head differences have much less error than the error associated with any single head measurement because some sources of error subtract (for example, drift, offset, temperature effect) and are equal or nearly equal for adjacent port readings. Therefore, a ±0.1 ft measurement accuracy was assumed for vertical head differences (and gradients) calculated between adjacent monitoring zones.

The precision of the fluid pressure measurement was determined by comparing fluid pressure measurements between consecutive profiles. Four repeat measurements were made at each of the six wells. A 0.03-psi mean difference between consecutive measurements and a 0.08-psi standard deviation indicates consistently high precision for the instrument. Measurement precision was again tested by comparing head values between paired ports, two measurement ports located in the same monitoring zone (fig. 10). Theoretically, the distribution of head within a monitoring zone should be uniform; therefore, any significant head difference between paired-port measurements provides evidence of either a malfunctioning measurement port or groundwater density variations. Paired-port head differences generally were small with an average value of 0.04 ft and a standard deviation of 0.16 ft. Relatively large head differences ranging from 0.37 to 0.97 ft, however, were observed between paired-ports in monitoring zone 15 of USGS 134. These large head differences are temporally variable and attributed to an improper seal while coupling the probe with port 20 and (or) a water density distribution within zone 15 that varied over space and time.

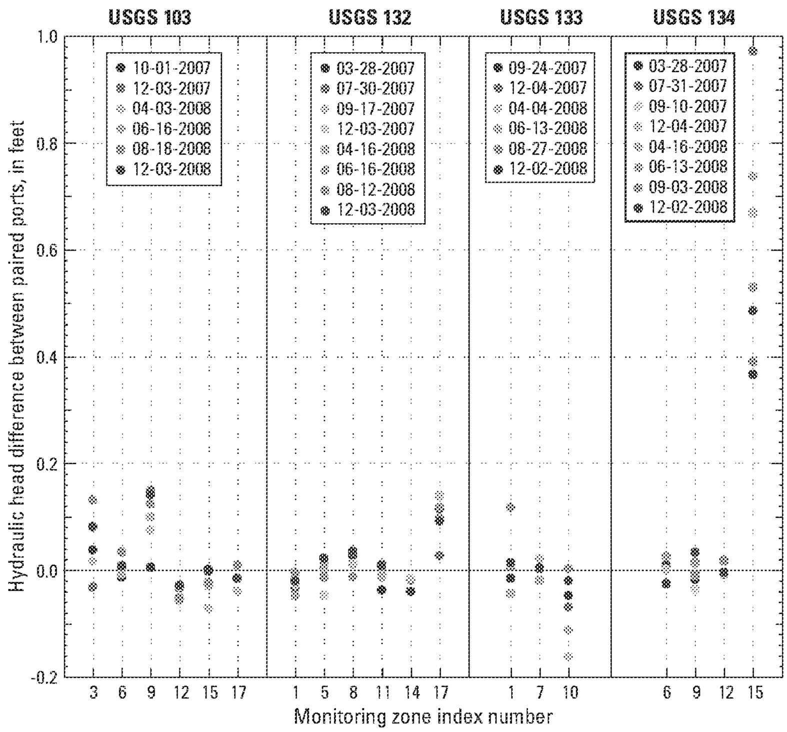

Figure 10. Hydraulic head differences between paired-ports, measurement ports in the same monitoring zone, in boreholes USGS 103, USGS 132, USGS 133, and USGS 134, Idaho National Laboratory, Idaho, 2007–08.

Hydraulic Head and Temperature Measurements

Hydraulic head and groundwater temperature measurements in the network of MLMSs are presented for 2007 and 2008. The six boreholes instrumented with MLMSs are USGS 103, 132, 133, 134, MIDDLE 2050A, and MIDDLE 2051 (fig. 1; table 1). Head and temperature measurements were recorded in 86 hydraulically isolated monitoring zones located 448.0 to 1,377.6 ft below land surface (table 2). Detailed descriptions of the geophysical traces, lithology log, completion log, and profile shapes are provided for each borehole. The profile shapes were analyzed temporally and spatially.

Table 1. Data for multilevel groundwater monitoring wells and boreholes, Idaho National Laboratory, Idaho, 2007–08.

[**Local name:** Local well identifier used in this study. **Latitude and Longitude:** Formatted in degrees, minutes, seconds, based on the North American Datum of 1927. **Land-surface altitude:** Based on the National Geodetic Vertical Datum of 1929 (NGVD 29). **Base of aquifer altitude:** Based on the NGVD 29 (Whitehead, 1992; Anderson and Liszewski, 1997). **Site No.:** Unique numerical identifier used to access well data (http://waterdata.usgs.gov/nwis). **Abbreviations:** ft, foot; ft bls, foot below land surface]

Local name	Latitude	Longitude	Land-surface altitude (ft)	Base of aquifer altitude (ft)	Hole depth (ft bls)	Site No.
USGS 103	43°27'13.57"	112°56'06.53"	5,007.42	2,470	1,307	432714112560701
USGS 132	43°29'06.68"	113°02'50.93"	5,028.60	2,540	1,238	432906113025001
USGS 133	43°36'05.50"	112°55'43.80"	4,890.12	3,960	818	433605112554301
USGS 134	43°36'11.15"	112°59'58.27"	4,968.84	3,960	949	433611112595801
MIDDLE 2050A	43°34'09.48"	112°57'05.38"	4,928.22	3,790	1,427	433409112570501
MIDDLE 2051	43°32'16.93"	113°00'49.38"	4,997.31	3,270	1,179	433217113004901

Table 2. Data for multilevel well completions, boreholes USGS 103, USGS 132, USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051, Idaho National Laboratory, Idaho, 2007–08.

[**Local name:** Local well identifier used in this study. **Zone No.:** Identifier used to locate monitoring zones. **Zone depth interval:** Depth to the bottom and top of a monitoring zone, the volumetric space between consecutive packers outside the multiport casing. **Port No.:** Identifier used to locate port couplings. **Port coupling depth:** Depth to the top of the measurement port coupling. **Site No.:** Unique numerical identifiers used to access port data (http://waterdata.usgs.gov/nwis). **Abbreviations:** ft bls, foot below land surface; ft, foot]

Local name	Zone No.	Zone depth interval			Port No.	Port coupling depth (ft bls)	Site No.
		Bottom (ft bls)	Top (ft bls)	Length (ft)			
USGS 103	1	1,279.4	1,257.4	22.0	1	1,258.0	432714112560702
	2	1,254.4	1,242.9	11.5	2	1,243.5	432714112560703
	3	1,239.9	1,184.4	55.6	3	1,209.7	432714112560704
					4	1,185.0	432714112560705
	4	1,181.4	1,115.2	66.2	5	1,115.8	432714112560706
	5	1,112.2	1,100.6	11.5	6	1,101.2	432714112560707
	6	1,097.6	1,063.2	34.5	7	1,086.8	432714112560708
					8	1,063.8	432714112560709
	7	1,060.2	1,045.5	14.7	9	1,046.1	432714112560710
	8	1,042.5	1,016.5	26.0	10	1,017.1	432714112560711
	9	1,013.5	958.0	55.4	11	992.9	432714112560712
					12	958.6	432714112560713
	10	955.0	948.4	6.6	13	949.0	432714112560714
	11	945.4	922.6	22.8	14	923.2	432714112560715
	12	919.6	891.6	28.0	15	908.7	432714112560716
					16	892.2	432714112560717
	13	888.6	862.6	26.0	17	863.2	432714112560718
	14	859.6	835.1	24.5	18	835.7	432714112560719
	15	832.1	766.9	65.2	19	801.9	432714112560720
					20	767.5	432714112560721
	16	763.9	694.3	69.7	21	694.9	432714112560722
	17	691.3	669.6	21.7	22	680.3	432714112560723
					23	670.2	432714112560724
USGS 132	1	1,213.6	1,152.3	61.3	1	1,173.0	432906113025001
					2	1,152.9	432906113025002
	2	1,149.3	1,144.1	5.2	3	1,144.7	432906113025003
	3	1,141.1	1,134.3	6.8	4	1,134.9	432906113025004
	4	1,131.3	1,046.1	85.3	5	1,046.7	432906113025005
	5	1,043.1	984.3	58.7	6	1,011.6	432906113025006
					7	984.9	432906113025007
	6	981.3	953.2	28.2	8	953.8	432906113025008
	7	950.2	938.4	11.8	9	939.0	432906113025009
	8	935.4	911.1	24.3	10	918.7	432906113025010
					11	911.7	432906113025011
	9	908.1	876.7	31.4	12	877.3	432906113025012
	10	873.7	866.8	6.8	13	867.4	432906113025013
	11	863.8	811.5	52.3	14	827.3	432906113025014
					15	812.1	432906113025015
	12	808.5	801.6	6.9	16	802.2	432906113025016
	13	798.6	790.1	8.5	17	790.7	432906113025017
	14	787.1	726.6	60.5	18	765.4	432906113025018
					19	727.2	432906113025019
	15	723.6	672.5	51.1	20	673.1	432906113025020
	16	669.5	662.6	6.9	21	663.2	432906113025021
	17	659.6	623.6	36.1	22	637.9	432906113025022
					23	624.2	432906113025023

Table 2. Data for multilevel well completions, boreholes USGS 103, USGS 132, USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051, Idaho National Laboratory, Idaho, 2007–08.—Continued

[**Local name:** Local well identifier used in this study. **Zone No.:** Identifier used to locate monitoring zones. **Zone depth interval:** Depth to the bottom and top of a monitoring zone, the volumetric space between consecutive packers outside the multiport casing. **Port No.:** Identifier used to locate port couplings. **Port coupling depth:** Depth to the top of the measurement port coupling. **Site No.:** Unique numerical identifiers used to access port data (http://waterdata.usgs.gov/nwis). **Abbreviations:** ft bls, foot below land surface; ft, foot]

Local name	Zone No.	Zone depth interval			Port No.	Port coupling depth (ft bls)	Site No.
		Bottom (ft bls)	Top (ft bls)	Length (ft)			
USGS 133	1	766.4	724.8	41.6	1	745.5	433605112554301
					2	725.4	433605112554302
	2	721.8	715.0	6.8	3	715.6	433605112554303
	3	712.0	698.6	13.4	4	699.2	433605112554304
	4	695.6	685.5	10.1	5	686.1	433605112554305
	5	682.5	618.2	64.3	6	618.8	433605112554306
	6	615.2	593.7	21.6	7	594.3	433605112554307
	7	590.7	555.5	35.2	8	569.6	433605112554308
					9	556.1	433605112554309
	8	552.5	539.1	13.4	10	539.7	433605112554310
	9	536.1	483.2	52.8	11	483.8	433605112554311
	10	480.2	448.0	32.3	12	469.1	433605112554312
					13	448.6	433605112554313
USGS 134	1	886.8	881.0	5.8	1	881.6	433611112595801
	2	878.0	871.0	7.0	2	871.6	433611112595802
	3	868.0	846.0	22.0	3	856.1	433611112595803
					4	846.6	433611112595804
	4	843.0	831.0	12.0	5	831.6	433611112595805
	5	828.0	821.0	7.0	6	821.6	433611112595806
	6	818.0	782.0	36.0	7	806.6	433611112595807
					8	782.6	433611112595808
	7	779.0	747.0	32.0	9	747.6	433611112595809
	8	744.0	723.0	21.0	10	723.6	433611112595810
	9	720.0	690.9	29.0	11	706.5	433611112595811
					12	691.5	433611112595812
	10	687.9	664.9	23.0	13	665.5	433611112595813
	11	661.9	654.9	7.0	14	655.5	433611112595814
	12	651.9	638.9	13.0	15	645.5	433611112595815
					16	639.5	433611112595816
	13	635.9	604.8	31.1	17	605.4	433611112595817
	14	601.8	592.8	9.0	18	593.4	433611112595818
	15	589.8	553.8	36.0	19	578.5	433611112595819
					20	554.4	433611112595820

Table 2. Data for multilevel well completions, boreholes USGS 103, USGS 132, USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051, Idaho National Laboratory, Idaho, 2007–08.—Continued

[**Local name:** Local well identifier used in this study. **Zone No.:** Identifier used to locate monitoring zones. **Zone depth interval:** Depth to the bottom and top of a monitoring zone, the volumetric space between consecutive packers outside the multiport casing. **Port No.:** Identifier used to locate port couplings. **Port coupling depth:** Depth to the top of the measurement port coupling. **Site No.:** Unique numerical identifiers used to access port data (http://waterdata.usgs.gov/nwis). **Abbreviations:** ft bls, foot below land surface; ft, foot]

Local name	Zone No.	Zone depth interval			Port No.	Port coupling depth (ft bls)	Site No.
		Bottom (ft bls)	Top (ft bls)	Length (ft)			
MIDDLE 2050A	1	1,377.6	1,267.5	110.1	1	1,268.1	433409112570501
	2	1,264.5	1,229.7	34.7	2	1,230.3	433409112570502
	3	1,226.7	1,179.7	47.0	3	1,180.3	433409112570503
	4	1,176.7	1,081.3	95.4	4	1,081.9	433409112570504
	5	1,078.3	1,043.6	34.7	5	1,044.2	433409112570505
	6	1,040.6	998.7	41.9	6	999.3	433409112570506
	7	995.7	843.1	152.6	7	843.7	433409112570507
	8	840.1	810.4	29.8	8	811.0	433409112570508
	9	807.4	790.0	17.4	9	790.6	433409112570509
	10	787.0	719.5	67.5	10	720.1	433409112570510
	11	716.5	706.4	10.2	11	707.0	433409112570511
	12	703.4	643.3	60.1	12	643.9	433409112570512
	13	640.3	623.7	16.6	13	624.3	433409112570513
	14	620.7	541.6	79.1	14	542.2	433409112570514
	15	538.6	464.9	73.7	15	516.8	433409112570515
MIDDLE 2051	1	1,176.5	1,140.3	36.2	1	1,140.9	433217113004901
	2	1,137.3	1,130.5	6.8	2	1,131.1	433217113004902
	3	1,127.5	1,090.5	37.0	3	1,091.1	433217113004903
	4	1,087.5	1,002.2	85.3	4	1,002.8	433217113004904
	5	999.2	879.4	119.8	5	880.0	433217113004905
	6	876.4	826.2	50.1	6	826.8	433217113004906
	7	823.2	791.9	31.4	7	792.5	433217113004907
	8	788.9	773.8	15.0	8	774.4	433217113004908
	9	770.8	748.4	22.4	9	749.0	433217113004909
	10	745.4	646.7	98.8	10	647.3	433217113004910
	11	643.7	612.2	31.5	11	612.8	433217113004911
	12	609.2	561.8	47.4	12	602.9	433217113004912

Quarterly Measurements

The 2-year multilevel monitoring program resulted in 88 profiles representing 1,552 individual measurements of head and temperature at the 6 MLMS boreholes (fig. 11; appendix E). With the exception of boreholes USGS 103 and 133, profiles were measured each quarter during the 2007 and 2008 calendar years; absent from USGS 103 and 133 are profiles for the first and second calendar quarters of 2007 because they were not installed until the third quarter. Throughout the 2-year monitoring campaign, head ranged from 4,418.9 to 4,463.6 ft at boreholes USGS 103 and 132, respectively, and water temperature ranged from 10.2 to 16.3 °C at boreholes USGS 132 and MIDDLE 2050A, respectively. As expected, the lowest head values were measured in the farthest downgradient boreholes at USGS 103 and 132, and the highest head values were in the farthest upgradient borehole at USGS 133 (fig. 4). Measured groundwater temperatures were well within the reported range for temperatures observed in the ESRP aquifer at or near the INL, 8.3 to 19.5 °C (Davis, 2008).

A comparison between the profile shapes at different boreholes shows a high level of variability among boreholes that is attributed to the aquifers complex basalt stratigraphy, proximity to aquifer recharge and discharge, and groundwater flow. The general shape of the profile in a borehole was, however, consistent among measurement dates (fig. 11). For example, a comparison between the March 2007 and December 2008 head measurements at borehole USGS 132 resulted in a 0.96 Pearson correlation coefficient (PCC). The closer the PCC is to either -1 or 1, the stronger the correlation between variables; therefore, a 0.96 PCC indicates a strong positive correlation between head profiles (that is, there was little change in the profile shape over time). To evaluate the correlation among all head or temperature profiles in a well requires the calculation of PCC for all permutations of profiles taken two at a time for each port; the minimum of these values reflects the poorest correlation between profiles in a borehole. For example, the 8 head profiles at borehole USGS 132 have 28 permutations. A PCC was calculated for each permutation and the minimum of these values was 0.90, indicating a strong positive correlation among all head profiles at borehole USGS 132. The minimum PCC values associated with head and temperature profiles at each borehole is summarized in table 3.

Minimum PCC values for head profiles ranged from 0.72 at borehole USGS 103 to 1.00 at boreholes USGS 133 and MIDDLE 2051 (table 3). The low minimum PCC among head profiles at borehole USGS 103 is attributed to its small vertical head differences, the maximum head range in a profile was 0.2 ft, and a relative uncertainty for head differences between adjacent zones of ±0.1 ft; under these circumstances, measurement error can produce a low PCC where a strong correlation exists. Among head profiles in borehole USGS 134 the minimum PCC also was low at 0.83 and partially due to the large head difference between paired ports in monitoring zone 15 (fig. 10). Excluding zone 15, head data from the analysis resulted in a USGS 134 minimum PCC of 0.89, indicating some level of variability in the profile shape over time. This temporal variability primarily occurs within the upper part of the borehole and provides evidence of a pressure response to mountain front recharge events. Boreholes USGS 132, USGS 133, MIDDLE 2050A, and MIDDLE 2051 resulted in minimum PCC values greater than or equal to 0.90, which suggests a strong positive correlation among head profiles. Calculation of the minimum PCC values for temperature profiles in a well excluded all data monitored prior to June 2008 because measurements collected during this period did not allow for temperature stabilization before final measurements were recorded, as indicated by the high variability of temperature measurements within the deepest ports (fig. 11). The minimum PCC values for temperature profiles were relatively strong and ranged from 0.89 to 1.00 at boreholes USGS 133 and 134, respectively, with a mean value of 0.97 (table 3).

Table 3. Minimum Pearson correlation coefficients for hydraulic head and temperature profiles at selected boreholes, Idaho National Laboratory, Idaho, 2007–08.

[**Local name:** Local well identifier used in this study. **Temperature:** Temperature profiles prior to June 2008 were excluded because water temperature in these profiles was not allowed to stabilize before final measurements were recorded.]

Local name	Pearson correlation coefficients	
	Hydraulic head	Temperature
USGS 103	0.72	0.99
USGS 132	.90	.96
USGS 133	1.00	.89
USGS 134	.83	1.00
MIDDLE 2050A	.92	.99
MIDDLE 2051	1.00	.96

Assuming that the profile shape in a borehole does not change with time allows a simplified analysis by focusing on a single head and temperature profile in each borehole. Only profiles constructed from measurements collected during the June 2008 measurement period were considered; this was the first time water temperatures were allowed to stabilize before final measurements were recorded. The June 2008 profiles for all six MLMSs are presented with their corresponding borehole information in figures 12–17. Borehole information includes four geophysical traces, a lithology log, and a multilevel completion log. The geophysical traces are:

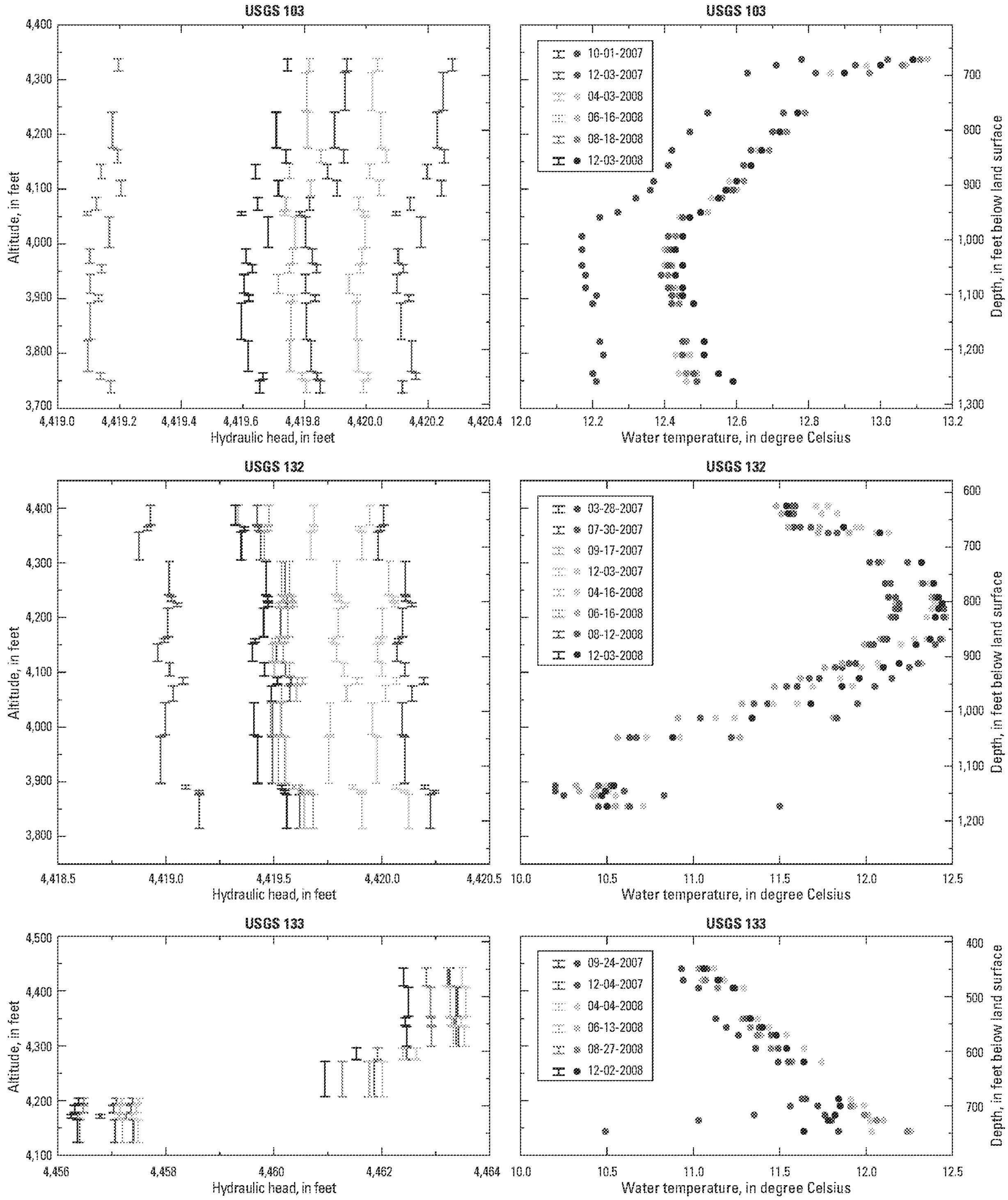

Figure 11. Vertical hydraulic head and water temperature profiles at boreholes USGS 103, USGS 132, USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051, Idaho National Laboratory, Idaho. Profiles are based on quarterly measurements made during 2007 and 2008.

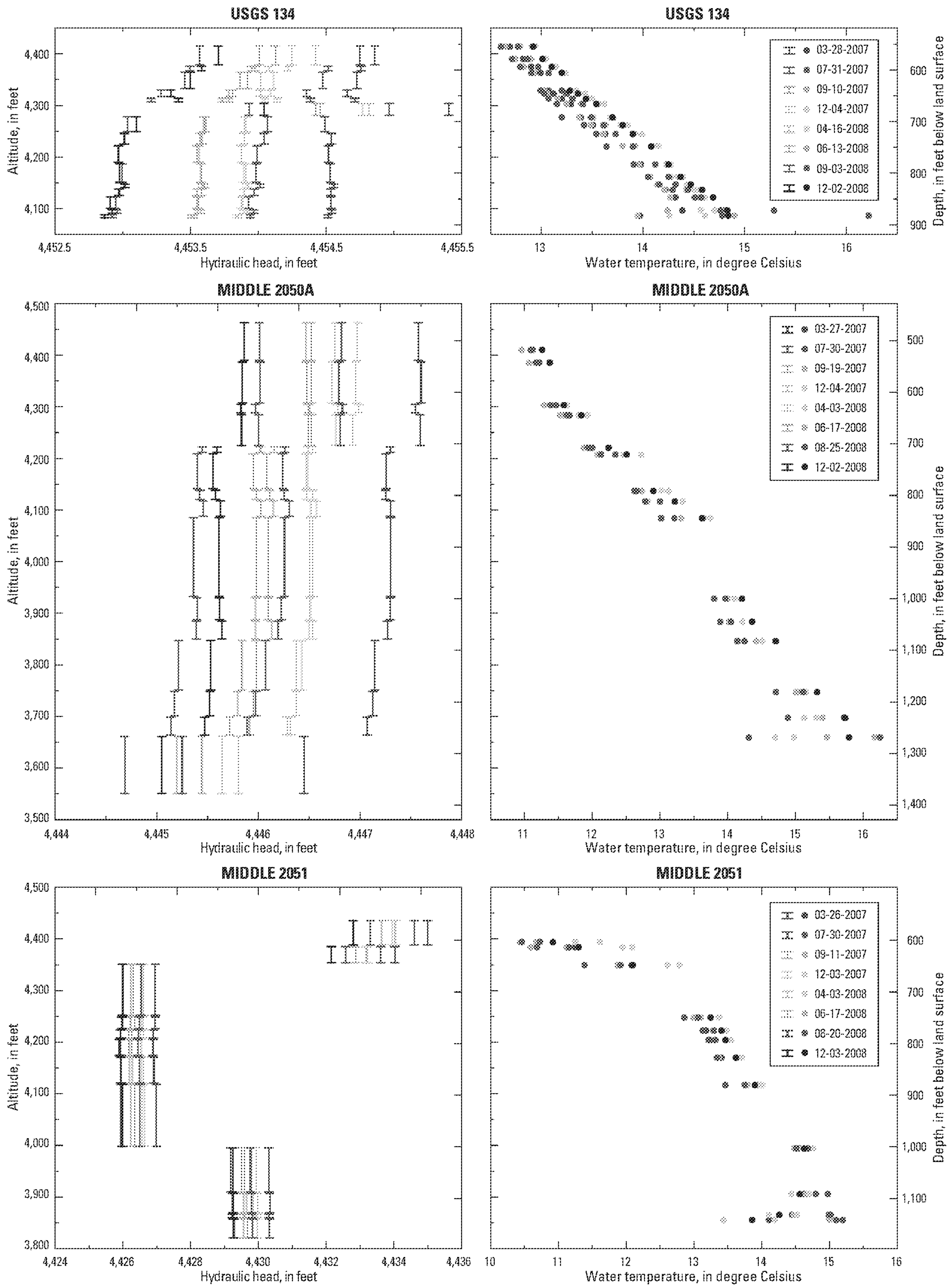

Figure 11.—Continued

1. Natural gamma, a measure of the gamma radiation emitted by the naturally occurring radioisotopes within the rock material comprising the borehole wall; where elevated natural gamma readings indicate the presence of a sedimentary layer.

2. Neutron, a measure of the hydrogen content of the rock, which is directly related to the porosity of the porous medium. A high neutron porosity indicates the presence of highly fractured basalt or sediment; whereas, a low neutron porosity would indicate an area of dense basalt.

3. Left and right caliper, uses three extendable spring loaded arms to measure drill-hole diameter at an accuracy of ±15 in. Changes in the regular drill-hole diameter may be due to collapse of the loose or highly fractured rock formations, areas unsuitable for packer placement.

4. Short-spaced and long-spaced gamma-gamma dual density, also known as the induced gamma-density, is a measure of the bulk density of a rock material near a borehole wall. The bulk density of a rock material is inversely related to its porosity.

All geophysical traces along with the borehole video and a visual inspection of the core were used to construct the generalized lithology log for each MLMS borehole (figs. 12–17; appendix F). The lithology logs for all boreholes were described using three lithologic units: (1) dense basalt, a rock material of moderate to low horizontal hydraulic conductivity and low to very low vertical hydraulic conductivity; (2) fractured basalt, a rock material of high to very high hydraulic conductivity; and (3) sediment, a fined grained sand and silt mixture of very low hydraulic conductivity. The percentage of lithologic composition in each borehole is provided in table 4. The reported effective hydraulic conductivity for the basalt and interbedded sediment that compose the ESRP aquifer at or near the INL ranges from about 1.0×10^{-2} to 3.2×10^{4} ft d^{-1} (Anderson and others, 1999). Reported porosity of the aquifer based on a cumulative distribution curve for more than 1,500 individual cores showed that the central 80 percent of samples had porosities of 0.08–0.25 (Knutson and others, 1992, figs. 4–10).

Table 4. Lithologic composition in selected boreholes, Idaho National Laboratory, Idaho, 2007–08.

[**Local name:** Local well identifier used in this study]

Local name	Percentage of lithologic unit		
	Dense basalt	Fractured basalt	Sediment
USGS 103	55	41	4
USGS 132	35	63	2
USGS 133	56	34	10
USGS 134	46	51	3
MIDDLE 2050A	51	35	14
MIDDLE 2051	64	33	3

The multilevel completion for each borehole (figs. 12–17) includes the location of measurement ports, packers, and monitoring zones. Measurement ports and monitoring zones are labeled using 'P' and 'Z', respectively, followed by a unique index number that increases with decreasing depth. For example, P3 identifies the third measurement port from the bottom of the hole, and Z4 the fourth monitoring zone from the bottom.

The shapes of the head profiles were analyzed using major head inflections. These inflections were identified using the difference between head measurements of adjacent monitoring zones. Head inflections were considered major where head differences exceeded the relative uncertainty for head differences between adjacent zones, ±0.1 ft. The head inflections were labeled using 'H' followed by a unique index number that increases with decreasing depth. For example, H1 identifies the vertical location of the first head inflection from the bottom of the hole. Vertical head gradients were calculated across the 3.0-ft-thick inflated packer length that separates monitoring zones (table 5; appendix G).

Table 5. Vertical hydraulic gradients at major inflection points for depth interval and hydraulic head profiles, Idaho National Laboratory, Idaho, June 2008.

[Major inflection points were identified using the difference between hydraulic head (head) measurements of adjacent monitoring zones. Head inflections were considered major where head differences exceeded the relative uncertainty for head differences between adjacent zones, ±0.1 feet. **Local name:** Local well identifier used in this study. **Inflection index No.:** Identifier used to locate major inflection points in the head profile. **Zone No.:** Identifiers used to locate monitoring zones. **Port No.:** Identifiers used to locate port couplings. **Depth interval:** Depth to the bottom and top of the inflated packer separating the adjacent monitoring zones. **Hydraulic head:** Negative and positive values indicate heads decreasing and increasing with depth, respectively. **Abbreviations:** ft bls, foot below land surface; ft, foot; ft ft^{-1}, foot per foot]

Local name	Inflection index No.	Zone No.	Port No.	Depth interval			Hydraulic head	
				Bottom (ft bls)	Top (ft bls)	Packer length (ft)	Difference (ft)	Gradient (ft ft^{-1})
USGS 133	H1	4, 5	5, 6	685.5	682.5	3.0	-4.6	-1.5
	H2	5, 6	6, 7	618.2	615.2	3.0	-.6	-.2
	H3	6, 7	7 – 9	593.7	590.7	3.0	-.9	-.3
	H4	9, 10	11 – 13	483.2	480.2	3.0	-.2	-.1
USGS 134	H1	9, 10	11 – 13	690.9	687.9	3.0	-.8	-.3
	H2	10, 11	13 – 14	664.9	661.9	3.0	.7	.2
MIDDLE 2050A	H1	1, 2	1, 2	1,267.5	1,264.5	3.0	-.5	-.2
	H2	4, 5	4, 5	1,081.3	1,078.3	3.0	-.2	-.1
	H3	11, 12	11, 12	706.4	703.4	3.0	-.3	-.1
MIDDLE 2051	H1	4, 5	4, 5	1,002.2	999.2	3.0	3.2	1.1
	H2	10, 11	10, 11	646.7	643.7	3.0	-6.5	-2.2
	H3	11, 12	11, 12	612.2	609.2	3.0	-.8	-.3

USGS 103

Borehole USGS 103 was established along the southern boundary of the INL about 5.5 mi south of the Central Facilities Area (CFA) (fig. 1). The land surface altitude and the estimated altitude of the base of the aquifer at this location are 5,007.42 and 2,470 ft, respectively (table 1). The borehole was air-rotary drilled in 1980 to a depth of 760 ft bls and completed as an 8-in. open interval monitoring well. In 2006, the borehole was deepened to 1,307 ft bls using rotary coring and then reamed to allow installation of a MP55 MLMS. Prior to reaming, the 6-in. casing was permanently set to a depth of 760 ft bls to allow proper packer inflation during the August 2007 MLMS installation; the MP55 system required a borehole diameter not to exceed 6.25 in. Perforations in the 6-in. casing were placed near monitoring zone 17 (fig. 12) to allow measurement ports 22 and 23 access to free moving groundwater; although, the vertical isolation of groundwater within zones 16 and 17 was compromised by the annular space between the 6-in. casing and the 8-in. borehole wall. Therefore, measurements collected from ports 21, 22, and 23 reflect a vertically averaged value of head for the interval between the water-table and the bottom of zone 16. The MP55 system extends to a depth of 1,279.4 ft bls and includes 23 measurement ports and 17 monitoring zones; 6 of these zones contain paired ports. Zone lengths range from 6.6 to 69.7 ft (fig. 12; table 2).

The lithology log of borehole USGS 103 (fig. 12; appendix F) shows units that range from 5 to 54 ft for dense basalt, 4 to 49 ft for fractured basalt, and 6 to 11 ft for sediment. The composition of lithologic units in the borehole is 55 percent dense basalt, 41 percent fractured basalt, and 4 percent sediment (table 4). Three sediment layers are in the borehole at depths of 849, 931, and 1,031 ft bls. Sediment recovered during drilling was described as eolian deposits of fine grained sand with silt. The layers of fractured and dense basalt are numerous and seem to be well distributed throughout the borehole.

No major inflections were identified in the USGS 103 head profile (fig. 12) indicating a high degree of vertical connectivity among adjacent fracture sets. The range of head in the profile was relatively small at 0.2 ft and indicates flow that is dominantly horizontal. Sediment layers in the borehole had no apparent affect on head. Water temperatures in the USGS 103 temperature profile (fig. 12) ranged from 12.4 to 13.1 °C and averaged 12.6 °C. Temperature generally decreases with depth in the upper part of the profile, and increases with depth in the lower part.

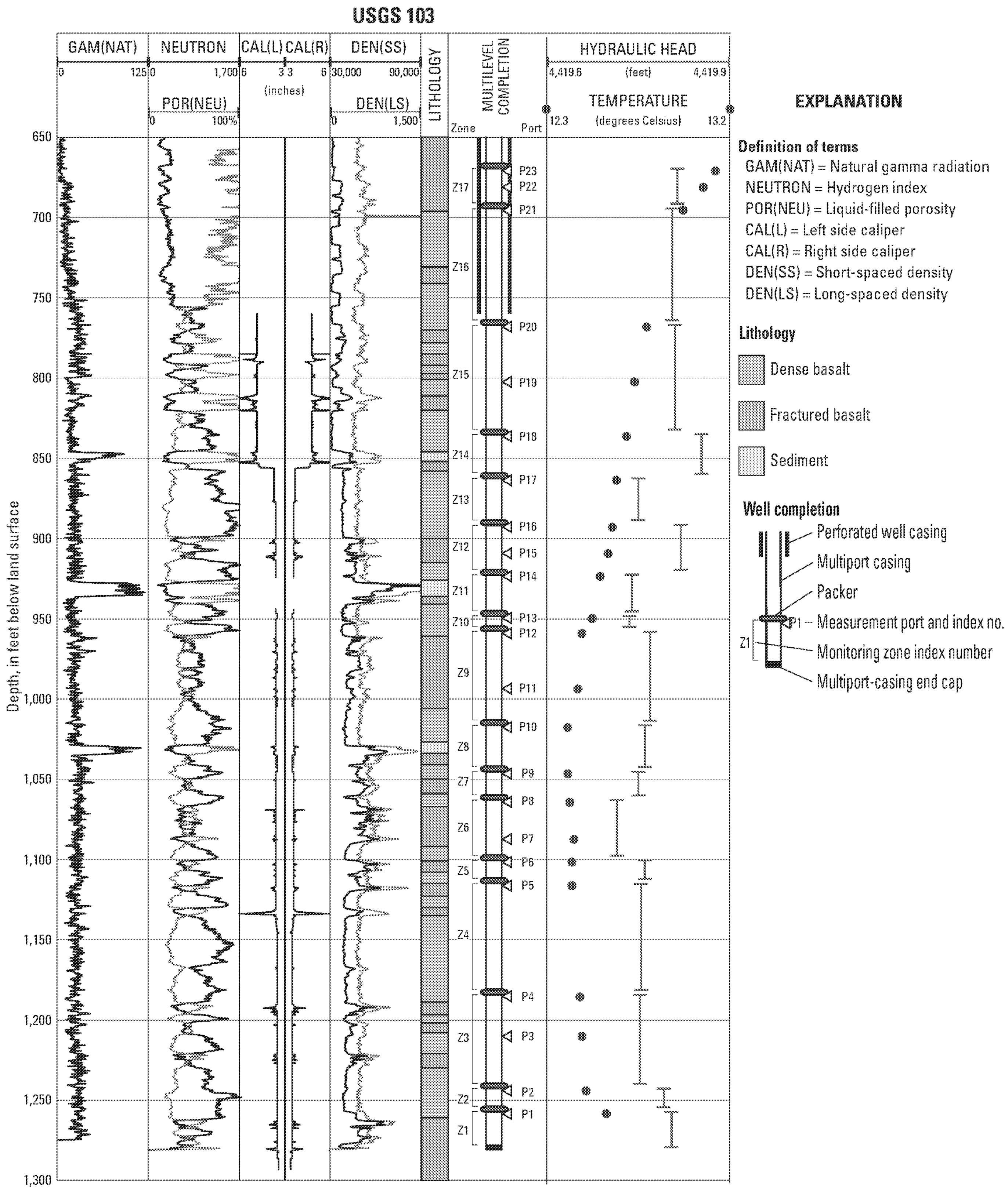

Figure 12. Geophysical traces of natural gamma, neutron, caliper, and gamma-gamma dual density; lithology log; multilevel completion; and hydraulic head and water temperature profiles for borehole USGS 103, Idaho National Laboratory, Idaho, June 2008.

USGS 132

Borehole USGS 132 was established approximately 0.9 mi south of the Radioactive Waste Management Complex (RWMC) (fig. 1). The land surface altitude and the estimated altitude of the base of the aquifer at this location are 5,028.60 and 2,540 ft, respectively (table 1). In 2004, the borehole was continuously cored to a depth of 1,238 ft bls, and in July 2006, an MP55 MLMS installed. The MP55 system extends to a depth of 1,213.6 ft bls and has a total of 23 measurement ports and 17 monitoring zones; 6 of these zones contain paired ports. Zone lengths range from 5.2 to 85.3 ft (fig. 13; table 2).

The lithology log of borehole USGS 132 (fig. 13; appendix F) shows units that range from 7 to 50 ft for dense basalt, 7 to 58 ft for fractured basalt, and 1 to 4 ft for sediment. The composition of lithologic units in the borehole is 35 percent dense basalt, 63 percent fractured basalt, and 2 percent sediment (table 4). Four sediment layers are in the upper part of the borehole at depths of 628, 677, 737, and 790 ft bls. Sediment recovered during drilling was described as eolian deposits of fine grained sand and silt. Layers of fractured and dense basalt are numerous with high concentrations of fractured basalt in the upper part of the borehole.

No inflections were identified in the USGS 132 head profile (fig. 13); this and the abundance of fractured basalt indicate a high degree of vertical connectivity among adjacent fracture sets. The range of head in the profile was relatively small at 0.3 ft and indicates flow that is dominantly horizontal. Water temperatures in the USGS 132 temperature profile (fig. 13) ranged from 10.5 to 12.5 °C and averaged 11.8 °C. A reversal in the temperature gradient occurs at an inflection point approximately 850 ft bls with temperatures decreasing with depth below the inflection point and increasing with depth above; this is opposite to that seen in borehole USGS 103.

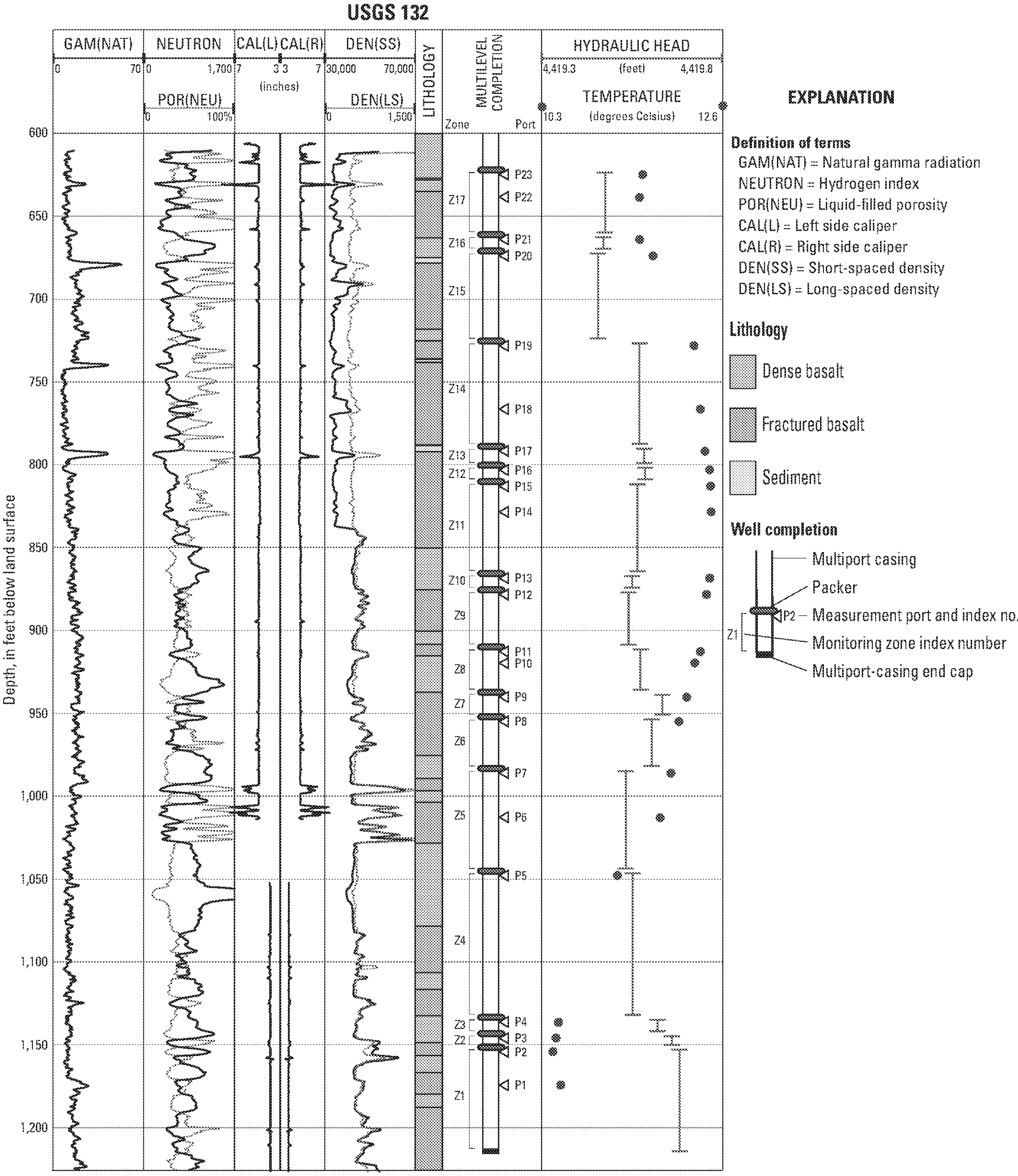

Figure 13. Geophysical traces of natural gamma, neutron, caliper, and gamma-gamma dual density; lithology log; multilevel completion; and hydraulic head and water temperature profiles for borehole USGS 132, Idaho National Laboratory, Idaho, June 2008.

USGS 133

Borehole USGS 133 was established approximately 1.9 mi north of the Idaho Nuclear Technology and Engineering Center (INTEC) (fig. 1). The land surface altitude and the estimated altitude of the base of the aquifer at this location are 4,890.12 and 3,960 ft, respectively (table 1). In 2005, the borehole was continuously cored to a depth of 818 ft bls, and in August 2007, an MP55 MLMS installed to a depth of 766.4 ft bls. The borehole was completed with 13 measurement ports and 10 monitoring zones; 3 of the zones contain paired ports. Zone lengths ranged from 6.8 to 64.3 ft (fig. 14; table 2).

The lithology log of borehole USGS 133 (fig. 14; appendix F) shows units that range from 4 to 54 ft for dense basalt, 6 to 40 ft for fractured basalt, and 1 to 33 ft for sediment. The composition of lithologic units in the borehole is 56 percent dense basalt, 34 percent fractured basalt, and 10 percent sediment (table 4). Two sediment layers less than 2-ft thick are at approximate depths of 670 and 699 ft bls, and one large 33-ft thick sediment layer is between 630 and 663 ft bls. Sediment recovered during drilling was described as a mixture of alluvial and eolian deposits of silty clay to coarse sand. The layers of fractured and dense basalt generally are thicker above the large sediment layer and thinner below.

Four major inflections were identified in the USGS 133 head profile: (1) H1, located across the 3-ft packer separating zones 4 and 5 with a -4.6 ft downward head loss; (2) H2, located between zones 5 and 6 with a -0.6 ft head loss; (3) H3, located between zones 6 and 7 with a -0.9 ft head loss; and (4) H4, located between zones 9 and 10 with a -0.2 ft head loss (fig 14; table 5). The source of inflections H1, H2, and H3 is the 33 ft sediment layer; where the sediment behaves as an aquitard, isolating fractured flow within the upper and lower parts of the aquifer. Note that the integrity of this aquitard was potentially compromised by allowing downward flow to bypass the sediment layer through the open borehole of monitoring zone 5. The H1 inflection directly coincides with this sediment layer and has a downward vertical hydraulic gradient of -1.5 ft ft^{-1}. Vertical gradients above the large sediment layer are somewhat less in magnitude at -0.2 and -0.3 ft ft^{-1} for the H2 and H3 inflections, respectively, and reflect a transition from low permeability sediment and dense basalt to high permeability fractured basalt. Head differences below the H1 inflection and above the H3 inflection remained relatively small indicating flow that is dominantly horizontal. The H4 inflection, in the upper part of the borehole, has a downward vertical gradient of -0.1 ft ft^{-1}. The H4 inflection results from the head difference between units of fractured basalt, a 40-ft layer in zone 9 and a 26-ft layer in zone 10, with vertical flow between these fracture units retarded by the 10-ft-thick layer of dense basalt that separates them. Water temperatures in the USGS 133 temperature profile (fig. 14) gradually increased with depth, ranged from 11.0 to 12.3 °C, and averaged 11.6 °C.

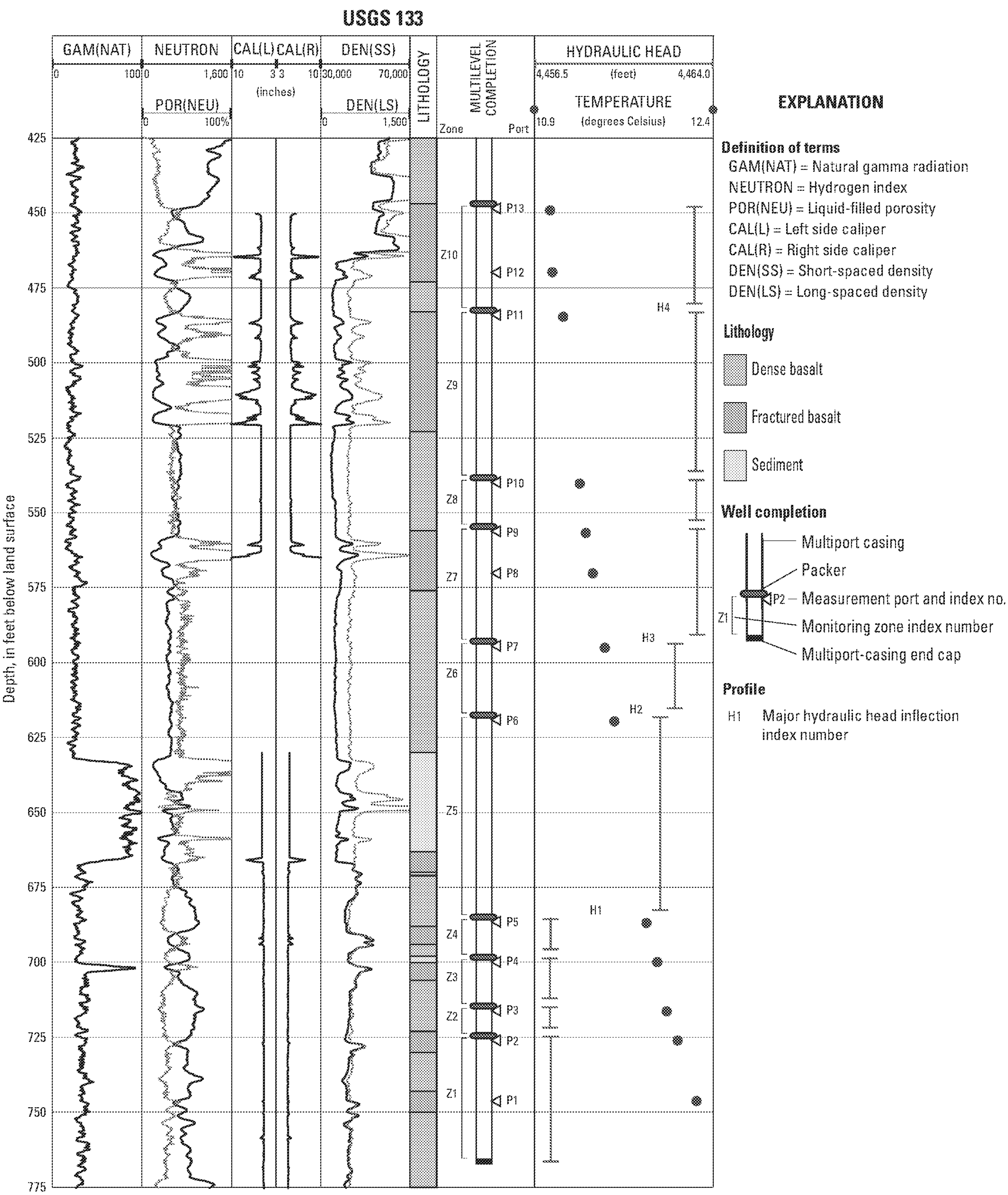

Figure 14. Geophysical traces of natural gamma, neutron, caliper, and gamma-gamma dual density; lithology log; multilevel completion; and hydraulic head and water temperature profiles for borehole USGS 133, Idaho National Laboratory, Idaho, June 2008.

USGS 134

Borehole USGS 134 was established approximately 1.8 mi northwest of the Advanced Test Reactor (ATR) (fig. 1). The land surface altitude and the estimated altitude of the base of the aquifer at this location are 4,968.84 and 3,960 ft, respectively (table 1). In 2005, the borehole was continuously cored to a depth of 949 ft bls, and in August 2006, an MP38 MLMS installed to a depth of 886.8 ft bls. The borehole was completed with 20 measurement ports and 15 monitoring zones; 5 of these zones contain paired ports. Zone lengths range from 5.8 to 36.0 ft (fig. 15; table 2).

The lithology log of borehole USGS 134 (fig. 15; appendix F) shows units that range from 5 to 39 ft for dense basalt, 2 to 27 ft for fractured basalt, and 1 to 4 ft for sediment. The composition of lithologic units in the borehole is 46 percent dense basalt, 51 percent fractured basalt, and 3 percent sediment (table 4). Four sediment layers in the borehole are at approximate depths of 618, 674, 732, and 835 ft bls. Two of the four sediment layers were recovered during drilling and were described as alluvial deposits of fine to course grained sand. The layers of fractured and dense basalt are numerous and appear well distributed throughout the borehole.

Two major inflections were identified in the USGS 134 head profile: (1) H1, located across the 3-ft packer separating zones 9 and 10 with a -0.8 ft downward head loss; and (2) H2, located between zones 10 and 11 with a 0.7 ft head gain (fig. 15; table 5). The vertical hydraulic gradients for the H1 and H2 inflections are -0.3 and 0.2 ft ft^{-1}, respectively, and result from a localized head increase in zone 10. This head increase probably is hydraulically isolated in zone 10 due to the relatively small 0.1 ft head difference between zone 9 and 11, and possibly due to fractures in this zone that are poorly connected to the larger hydraulic system. Excluding zone 10, the variability in head was small with a range of 0.7 ft. Vertical head remained relatively stable below H1 and gradually decreased with depth above H2. Water temperatures in the USGS 134 temperature profile (fig. 15) gradually increased with depth, ranged from 12.8 to 14.9 °C, and averaged 13.7 °C.

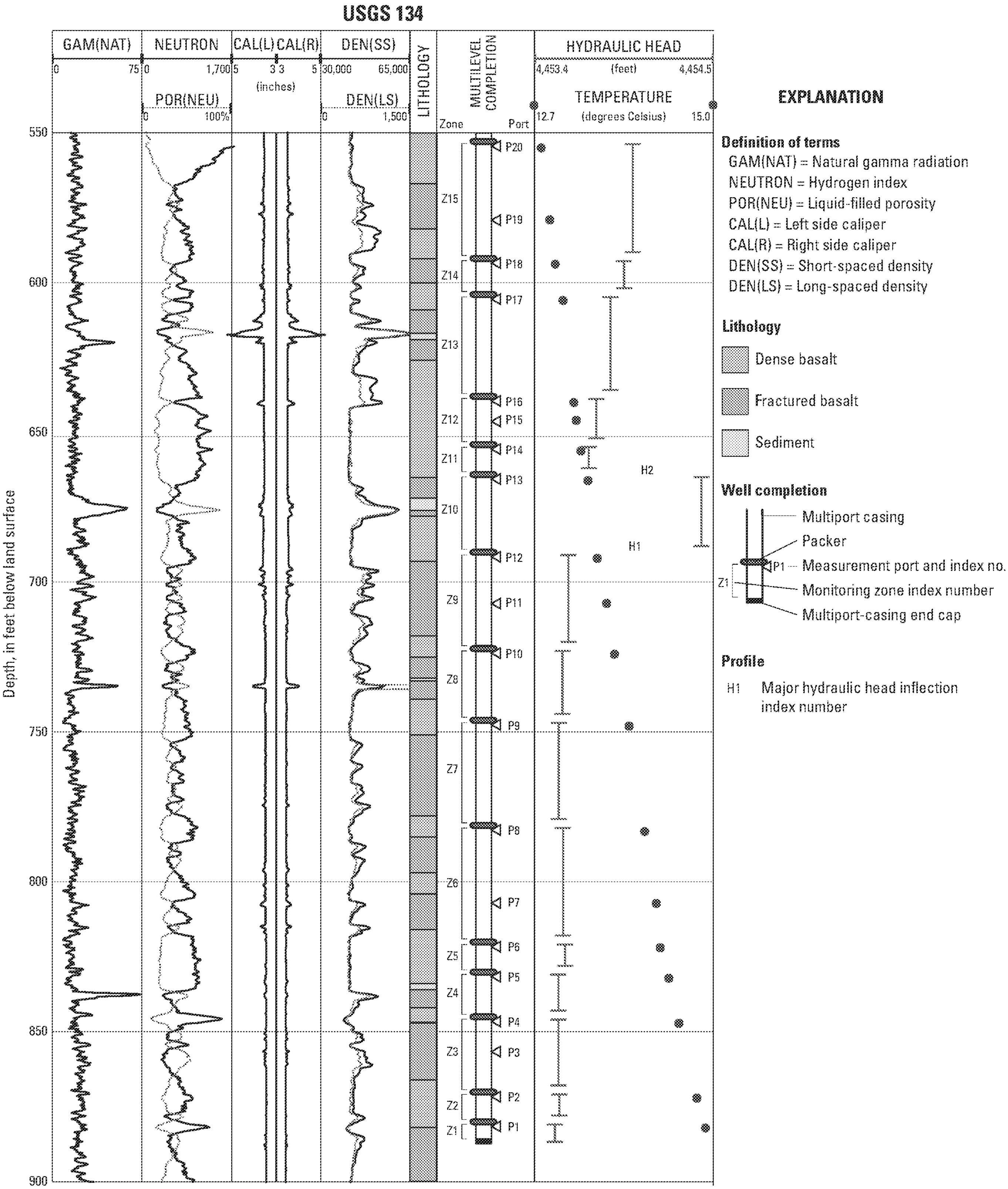

Figure 15. Geophysical traces of natural gamma, neutron, caliper, and gamma-gamma dual density; lithology log; multilevel completion; and hydraulic head and water temperature profiles for borehole USGS 134, Idaho National Laboratory, Idaho, June 2008.

MIDDLE 2050A

Borehole MIDDLE 2050A was established approximately 0.8 mi west of the Idaho Nuclear Technology and Engineering Center (INTEC) and 0.22 mi southeast of the Big Lost River (fig. 1). The land surface altitude and the estimated altitude of the base of the aquifer at this location are 4,928.22 and 3,790 ft, respectively (table 1). In 2005, the borehole was continuously cored to a depth of 1,427 ft bls, and in September 2005 an MP55 MLMS was installed to a depth of 1,377.6 ft bls. The borehole was completed with 15 measurement ports and 15 monitoring zones. Zone lengths range from 10.2 to 152.6 ft (fig. 16; table 2).

The lithology log of borehole MIDDLE 2050A (fig. 16; appendix F) shows units that range from 5 to 57 ft for dense basalt, 2 to 32 ft for fractured basalt, and 1 to 100 ft for sediment. The composition of lithologic units in the borehole is 51 percent dense basalt, 35 percent fractured basalt, and 14 percent sediment (table 4). Seven sediment layers in the borehole are at depths of 547, 747, 907, 1,056, 1,117, 1,190, and 1,330 ft bls. The largest of these layers is approximately 100-ft thick and accounts for 88 percent of the geologic material within zone 1. Layers of fractured and dense basalt are numerous with a slightly higher concentration of fractured basalt layers from 750 to 1,000 ft bls.

Three major inflections were identified in the MIDDLE 2050A head profile: (1) H1, located across the 3-ft packer separating zones 1 and 2 with a -0.5 ft downward head loss; (2) H2, located between zones 4 and 5 with a -0.2 ft head loss; and (3) H3, located between zones 11 and 12 with a -0.3 ft head loss (fig. 16, table 5). The vertical hydraulic gradient of the H1 inflection was -0.2 ft ft^{-1} and coincides with the 100-ft-thick layer of sediment. The head in zone 1 likely is controlled by the units of fractured basalt above and below this sediment layer, where flow is allowed to bypass the low permeability sediment through the open borehole. The low head in zone 1 suggests that flow is impeded by sediment-filled fractures with no distinct interface between lithologic units. The H2 and H3 inflections have vertical hydraulic gradients of -0.1 ft ft^{-1}, and coincide with layers of low-permeability sediment; where the sediment at these locations obstruct the vertical connectivity between adjacent fracture sets. Head differences between the major inflections and above the H3 inflection remained relatively small and indicate flow that is dominantly horizontal. The incremental head decrease with depth in the borehole indicates the potential for downward flow; however, this would require a loss in the integrity of the sediment layers. Water temperatures in the MIDDLE 2050A temperature profile (fig. 16) gradually increased with depth, ranged from 11.1 to 16.2 °C, and averaged 13.2 °C.

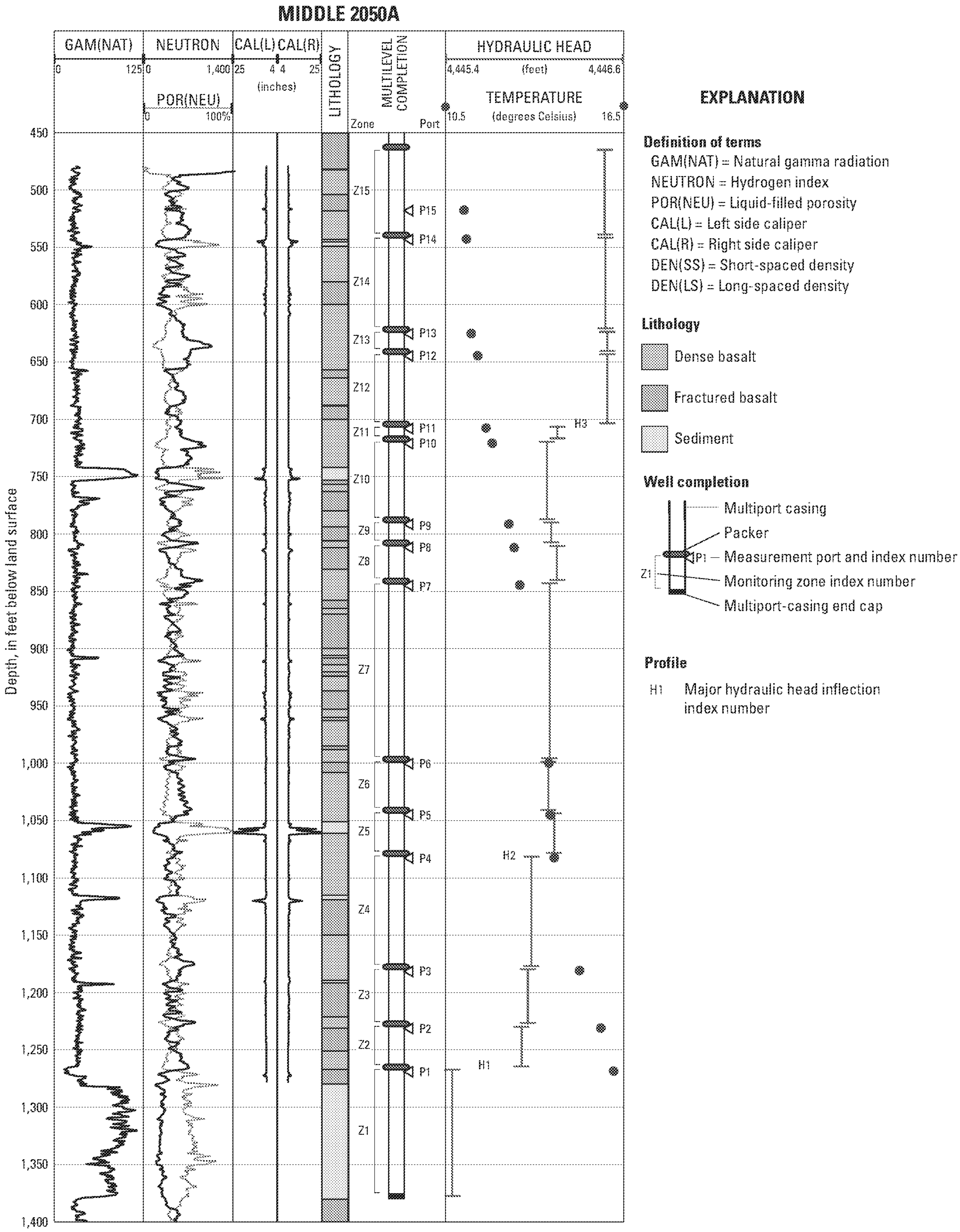

Figure 16. Geophysical traces of natural gamma, neutron, caliper, and gamma-gamma dual density; lithology log; multilevel completion; and hydraulic head and water temperature profiles for borehole MIDDLE 2050A, Idaho National Laboratory, Idaho, June 2008.

MIDDLE 2051

Borehole MIDDLE 2051 was established approximately 2.75 mi northeast of the RWMC and 0.16 mi southeast of the Big Lost River (fig. 1). The land surface altitude and the estimated altitude of the base of the aquifer at this location are 4,997.31 and 3,270 ft, respectively (table 1). In 2005, the borehole was continuously cored to a depth of 1,179 ft bls, and in September 2005, an MP55 MLMS was installed to a depth of 1,176.5 ft bls. The borehole was completed with 12 measurement ports and 12 monitoring zones. Zone lengths range from 6.8 to 119.8 ft (fig. 17; table 2).

The lithology log of borehole MIDDLE 2051 (fig. 17; appendix F) shows units that range from 1 to 76 ft for dense basalt, 1 to 34 ft for fractured basalt, and 1 to 7 ft for sediment. The composition of lithologic units within the borehole is 64 percent dense basalt, 33 percent fractured basalt, and 3 percent sediment (table 4). Five sediment layers in the upper part of the borehole are at depths of 620, 632, 673, 703, and 712 ft bls, and one sediment layer deeper in the borehole at a depth of 1,008 ft bls. Sediment recovered during drilling was described as eolian deposits of clay to fine grained sand, with clay being the predominant geologic material in the upper two sediment layers. Fractured basalt layers are clustered in the borehole and separated by thick layers of dense basalt that are interspersed with thin layers of sediment.

Three major inflections were identified in the MIDDLE 2051 head profile: (1) H1, located across the 3-ft packer separating zones 4 and 5 with a 3.2 ft downward head gain; (2) H2, located between zones 10 and 11 with a -6.5 ft head loss; and (3) H3, located between zones 11 and 12 with a -0.8 ft head loss (fig. 17; table 5). The H1 inflection has a vertical hydraulic gradient of 1.1 ft ft^{-1} and coincides with layers of fractured basalt separated by a 5-ft-thick layer of sediment and a 75-ft-thick layer of dense basalt (zone 5). The low permeability associated with these layers creates a hydraulic disconnect between the high permeability fracture sets above and below zone 5. The H2 and H3 inflections have vertical hydraulic gradients of -2.2 and -0.3 ft ft^{-1}, respectively, and also result from a restriction in vertical connectivity; where fracture sets coinciding with zones 10 and 12 are hydraulically isolated from one another by two layers of low permeability sediment (5- and 7-ft thick) within zone 11. Head differences below the H1 inflection and between the H1 and H2 inflections remained relatively small, indicating flow that is dominantly horizontal.

Supporting evidence for the isolation of fractured flow between confining units is provided by the MIDDLE 2051 temperature profile (fig. 17). Water temperature differences between adjacent monitoring zones were largest at locations of major head inflections. For example, water temperature gains of 1.2 °C between zones 4 and 5, and 1.7 °C between zones 9 and 10 coincided with the H1 and H2 head inflections, respectively. Below the H1 inflection and between H1 and H2 inflection, temperature differences remained relatively small and indicate high vertical connectivity between fractures. Water temperature for the entire profile generally decreased with depth, ranged from 11.1 to 15.0 °C, and averaged 13.2 °C.

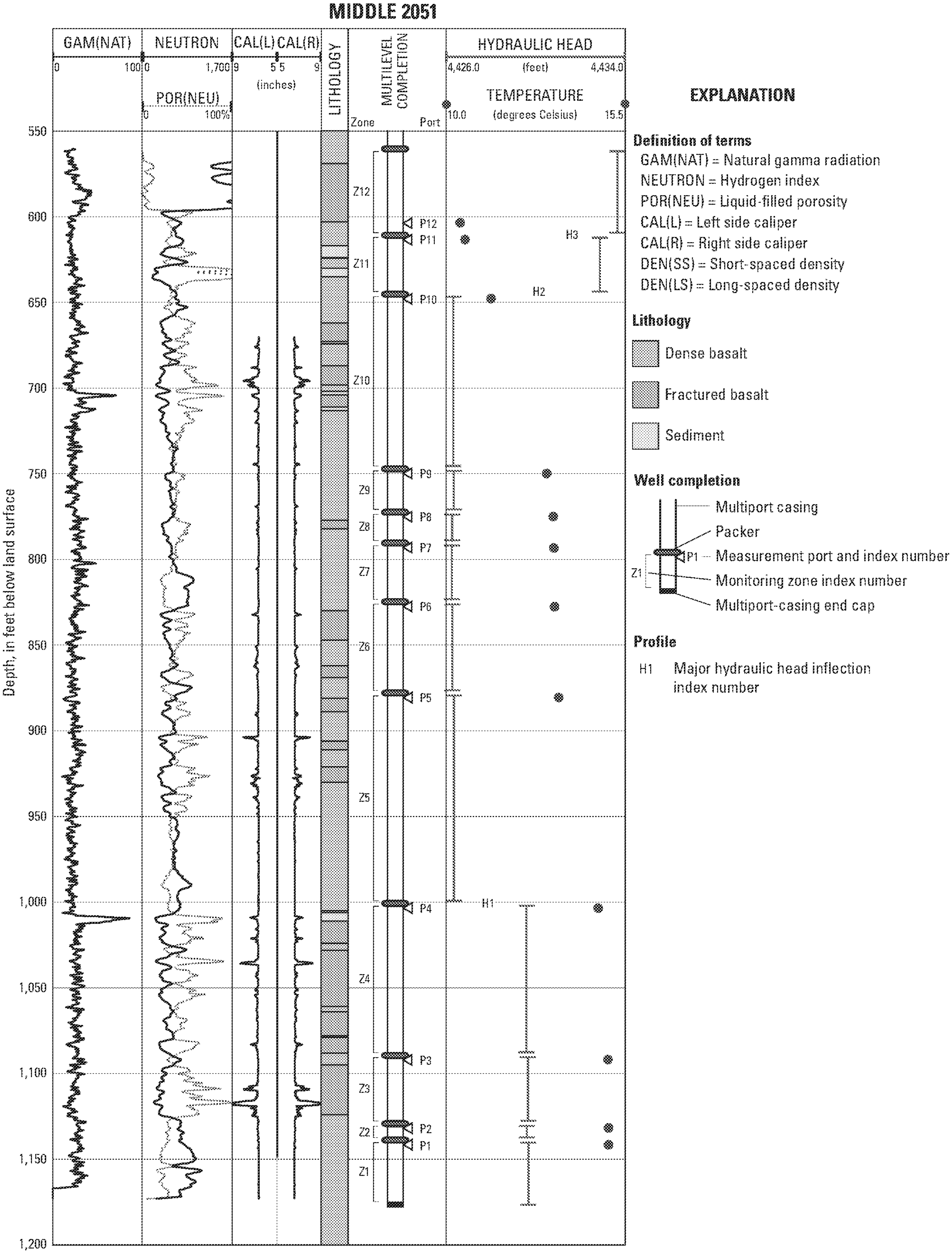

Figure 17. Geophysical traces of natural gamma, neutron, caliper, and gamma-gamma dual density; lithology log; multilevel completion; and hydraulic head and water temperature profiles for borehole MIDDLE 2051, Idaho National Laboratory, Idaho, June 2008.

Profile Comparison Among Boreholes

The June 2008 head and temperature profiles were compared between boreholes in an effort to better understand the groundwater flow system near the INL. The lithologic logs and profiles for all MLMS boreholes are shown in figure 18. To facilitate the comparison of head profiles among MLMSs, head values were normalized to the mean head value. The mean-shifted hydraulic head of a profile, $\hat{H}$, is expressed as

$$\hat{H}_i = H_i - \overline{H} \qquad \text{for } i = 1,\ldots,m, \tag{5}$$

where

H_i is the head measurement at port i in feet (ft);

m is the total number of port head measurements in the MLMS;

$\overline{H}$ is the mean head value in the profile (table 6) in ft, as defined as

$$\overline{H} = \frac{1}{m}\sum_{i=1}^{m} H_i. \tag{6}$$

The degree of vertical head change in a profile was evaluated using the range of its head measurements (table 6). The head range was lowest in boreholes USGS 103 and 132 at 0.2 and 0.3 ft, respectively. These are the only MLMS boreholes located in the volcanic highlands (fig. 1), an area of concentrated volcanic vents and fissures (Anderson and others, 1999, p. 13; Hughes and others, 1999, p. 145). Heads in these boreholes may coincidentally be close to one another, regardless of poor connectivity, or may indicate a high level of vertical connectivity in the fractured basalt; the lithology of boreholes USGS 103 and 132 include 41 and 63 percent fractured basalt, respectively (table 4).

All other MLMS boreholes are in the Big Lost Trough (fig. 1), an area that contains significantly greater quantities of sediment than other parts of the study area (Anderson and Liszewski, 1997). The highest head range at 6.2 and 7.4 ft were in boreholes USGS 133 and MIDDLE 2051, respectively. The large head ranges for these boreholes are attributed to poor vertical connectivity between fracture networks of adjacent units. For example, the large sediment layer in borehole USGS 133 accounts for 99.7 percent of the head change in the borehole. In zones that are primarily composed of fractured basalt, the vertical head differences remained relatively small and flow was dominantly horizontal. For example, in borehole USGS 133 the head range below the H1 inflection and above the H3 inflection was 0.1 and 0.2 ft, respectively (fig. 14). Relatively moderate head ranges at 0.9 and 1.0 ft were in boreholes USGS 134 and MIDDLE 2050A, respectively. In borehole USGS 134, head values gradually decreased with depth above the H2 inflection and remain relatively constant below; whereas, in borehole MIDDLE 2050A, head values incrementally decrease with depth and remain relatively constant between large sediment layers (figs. 15 and 16).

Table 6. Summary of depth range, hydraulic head statistics, water temperature statistics, water-level depth, and saturated thickness of the aquifer at each borehole, Idaho National Laboratory, Idaho, June 2008.

[**Local name:** Local well identifier used in this study. **Depth interval:** Measured from the top of the uppermost monitoring zone to the bottom of the lowest zone. **Mean hydraulic head:** Based on the National Geodetic Vertical Datum of 1929. **Saturated aquifer thickness:** Determined by subtracting the water-level depth from the aquifer thickness (appendix A). **Abbreviations:** ft, foot; °C, degrees Celsius; ft bls, foot below land surface]

Local name	Depth interval (ft)	Hydraulic head statistics		Water temperature statistics		Water-level depth (ft bls)	Saturated aquifer thickness (ft)
		Mean (ft)	Range (ft)	Mean (°C)	Range (°C)		
USGS 103	610	4,419.8	0.2	12.6	0.7	584.63	1,950
USGS 132	590	4,419.6	.3	11.8	2.0	607.10	1,880
USGS 133	318	4,460.7	6.2	11.6	1.2	427.61	500
USGS 134	333	4,453.7	.9	13.7	2.1	513.70	500
MIDDLE 2050A	913	4,446.1	1.0	13.1	5.0	479.94	660
MIDDLE 2051	615	4,428.6	7.4	13.2	4.6	569.48	1,160

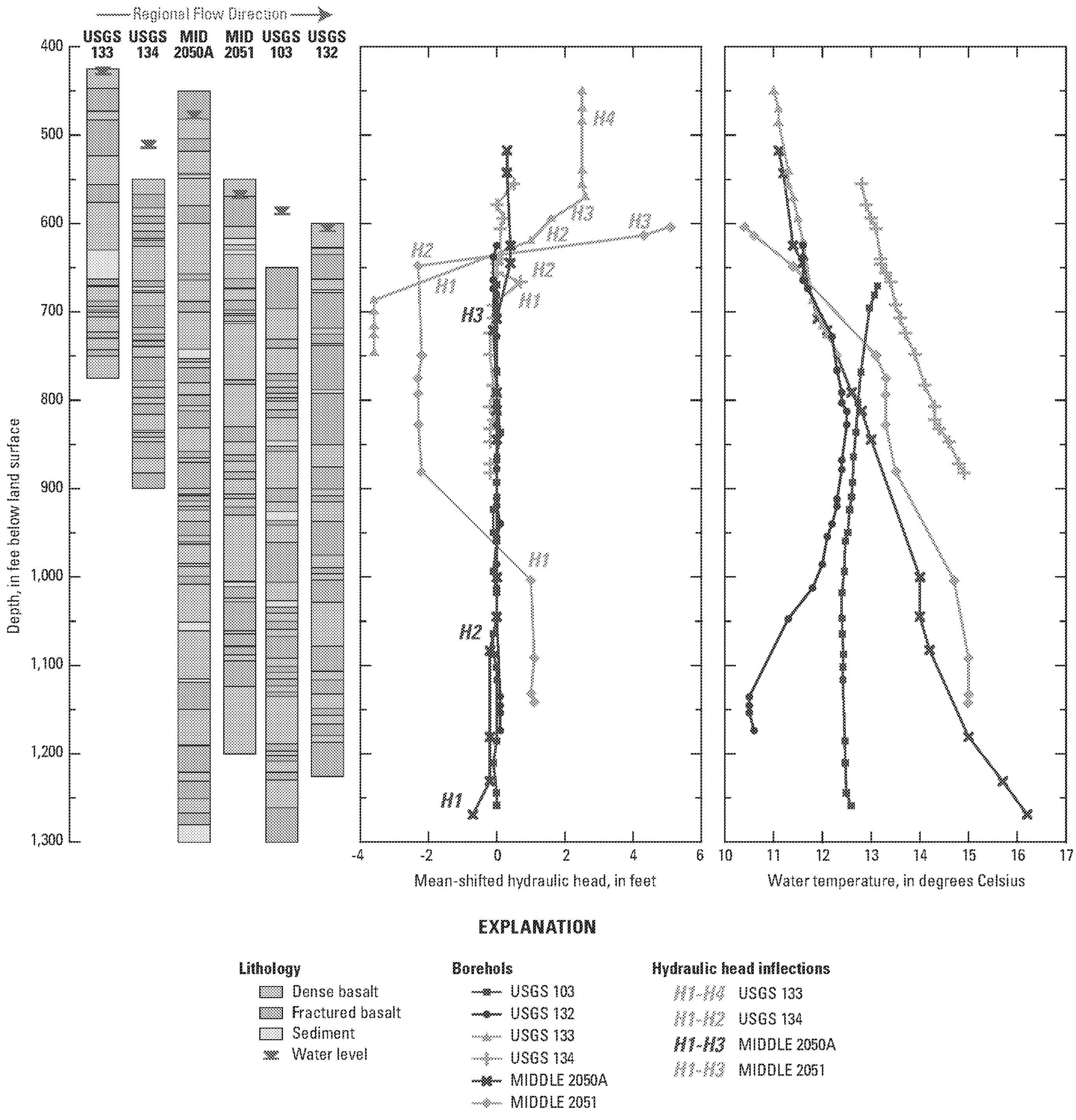

Figure 18. Comparison among borehole lithology logs and mean-shifted hydraulic head and water temperature profiles for boreholes USGS 103, USGS 132, USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051, Idaho National Laboratory, Idaho, June 2008.

Low vertical gradients generally indicate potential vertical connectivity and flow, and large gradient inflections indicate zones of relatively lower vertical connectivity, where vertical flow is potentially retarded. Major head inflections typically coincided with low permeability sediment layers; however, the presence of a sediment layer was not sufficient for identifying the location of a major head change in a borehole. For example, a 5-ft-thick sediment layer at a depth of 1,009 ft bls in borehole MIDDLE 2051 produced a 3.2 ft head shift; whereas, a 10-ft-thick sediment layer in borehole USGS 103, at an approximate depth of 931 ft bls, had no apparent effect on head. Without knowing the true areal extent and transmissivity of lithologic units, it is difficult to determine where head changes might occur in a borehole. The determination is especially difficult in the ESRP aquifer because of its high level of heterogeneity, which is indicated by the large variability in profile shapes among boreholes.

In an idealized aquifer-aquitard system, where groundwater is mostly confined in aquifers and flow is dominantly horizontal, the temperature profile is dominated by upward conductive heat transfer and distributed linearly. When confining layers are not perfectly impervious, however, the temperature profile will be affected by convective heat transfer resulting from the vertical movement of groundwater (Bredehoeft and Papadopulos, 1965; Ge, 1998). Temperature profiles in boreholes USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051 (fig. 18) mostly follow a linear conductive trend with temperatures increasing with depth. There is, however, evidence of downward convective heat transfer in the lower part of the MIDDLE 2050A temperature profile. In borehole MIDDLE 2051, the limited vertical connectivity between adjacent aquifer units produces a strong linear conductive trend; however, within each aquifer unit convective heat transfer dominates and temperatures remain relatively stable. The higher overall temperatures, by approximately 1.5 °C, in borehole USGS 134 are attributed to its close proximity to the northwest mountain front, where the thickness of the saturated aquifer is relatively thin and groundwater velocities relatively small.

In boreholes USGS 103 and 132, temperature profiles were mostly dominated by convective heat transfer, where fluid flow through the fractured media significantly altered the geothermal field. The small temperature range in borehole USGS 103 indicates good vertical connectivity among highly permeable fractures allowing for a reversal of the natural heat convection gradient in the upper half of borehole USGS 103. In borehole USGS 132, temperatures in the upper part of the borehole follow a linear conductive trend with temperature increasing with depth; this trend reverses in the lower part of the borehole and temperatures decrease with depth. This decrease with depth is attributed to the location of the borehole in a transition area where the saturated aquifer thickness (table 6) and transmissivity rapidly increase and flow has a downward component.

Evidence of this downward movement is provided by the detection of wastewater constituents in the deeper zones of borehole USGS 132 (Bartholomay and Twining, 2010). Temperature profiles for the upgradient MLMS boreholes (that is, USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051) follow a linear conductive trend where water temperatures increase with depth. As indicated by the USGS 132 temperature profile, therefore, colder water is channeled downward as it moves through the transition area. The linear conductive trend in the upper part of borehole USGS 132 suggests that multiple groundwater sources are located in the transition area; where low-velocity tributary valley water mixes with high-velocity regional groundwater (Cecil and others, 2000; Busenberg and others, 2001). The vertical head and temperature characteristics of the regional groundwater are best reflected in the profiles of borehole USGS 103, the farthest MLMS borehole from the tributary valleys along the northwest edge of the plain. The intersection of these two water types and an increase in downward flow contribute to the gradient reversal indicated in the USGS 132 temperature profile.

The temporal correlation among MLMSs was analyzed using the normalized mean hydraulic head, $\overline{\mathrm{H}}$; these values of head were calculated for each MLMS and expressed as

$$\hat{\overline{\mathrm{H}}}_t = \frac{\overline{\mathrm{H}}_t - \overline{\overline{\mathrm{H}}}}{s} \qquad \text{for } t = 1, \ldots, n, \tag{7}$$

where

$\overline{\mathrm{H}}_t$ is the profiles mean head for measurement event t in feet (ft) (eq. 6);

n is the total number of measurement events at the borehole;

$\overline{\overline{\mathrm{H}}}$ is the mean of the profiles mean head values for all measurement events in ft and defined as

$$\overline{\overline{\mathrm{H}}} = \frac{1}{n}\sum_{t=1}^{n}\overline{\mathrm{H}}_t, \tag{8}$$

s is the standard deviation of the profiles mean head values for all measurement events in feet and defined as

$$s = \sqrt{\frac{1}{n}\sum_{t=1}^{n}\left(\overline{\mathrm{H}}_t - \overline{\overline{\mathrm{H}}}\right)}. \tag{9}$$

The values of $\hat{\bar{H}}$ for each of the MLMS boreholes (fig. 19; appendix H) suggests a moderate positive correlation among all boreholes, which reflects regional fluctuations in water levels in response to seasonal climatic changes. The temporal correlation is stronger when the location of boreholes in the aquifer is considered. For example, boreholes USGS 103 and USGS 132 are in an area of highly permeable media with a relatively large saturated thickness, and a relatively rapid groundwater flow. As expected, the correlation between these two wells is strongly positive with a temporal trend that differs slightly from the other boreholes.

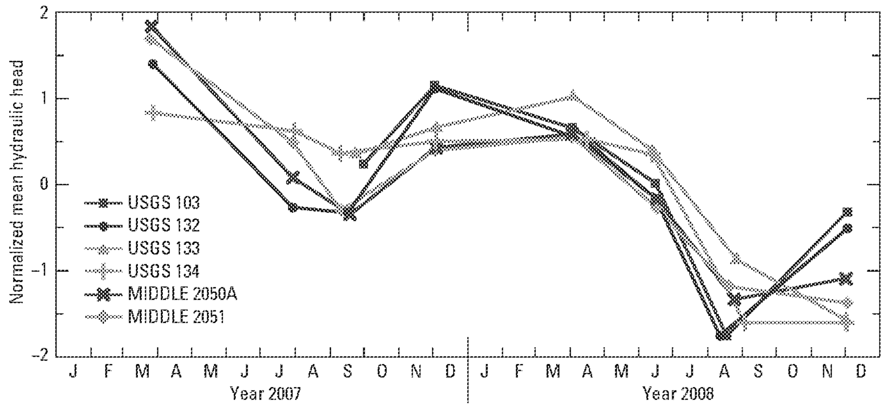

Figure 19. Quarterly values of the normalized mean hydraulic head at boreholes USGS 103, USGS 132, USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051, Idaho National Laboratory, Idaho, 2007 and 2008.

Summary

During 2007 and 2008, quarterly depth-discrete measurements of hydraulic head (head) and water temperature were collected from multilevel monitoring systems (MLMSs) installed in six boreholes at the Idaho National Laboratory (INL) in cooperation with the U.S. Department of Energy. The cored boreholes are located in the fractured basalts and interbedded sediments of the eastern Snake River Plain aquifer and were completed to depths ranging from 818 to 1,427 ft below land surface. Head and temperature measurements were recorded in 86 hydraulically isolated monitoring zones located 448.0 to 1,377.6 ft below land surface. The MLMS provides a necessary approach for measurement of heads in the aquifer system, which is required as part of the characterization of the areal extent of contaminant plumes at the INL. Completion depths for MLMS boreholes exceed those of the average INL monitoring wells; therefore, additional information on deep flow and contaminant transport conditions will assist ongoing efforts to better characterize the full extent of downward plume migration in the aquifer.

The multilevel monitoring systems are composed of variable length segments of plastic casing, packers, couplings, and valved measurement ports. A wireline-operated sampling probe records fluid pressure and temperature at measurement port inlet valves in each monitoring zone. Recorded data are transmitted to the surface using a communications cable and recorded on a datalogger. Measurement ports typically were paired within a single monitoring zone to evaluate the precision of fluid pressure and temperature measurements.

Head values were calculated using the measured values of fluid pressure and temperature recorded by the sampling probe, atmospheric or barometric pressure recorded at the land surface, and the altitude of the pressure transducer sensor at each measurement port coupling. The calculation of head is most sensitive to fluid pressure and the altitude of the pressure transducer sensor and less sensitive to barometric pressure and water temperature. An analysis of errors associated with the head calculation determined the accuracy of an individual head measurement at ±2.3 ft. Many sources of measurement error are diminished when considering the differences between two closely-spaced readings of head; therefore, a ±0.1 ft measurement accuracy was assumed for vertical head differences (and gradients) calculated between adjacent monitoring zones. Repeatability of head measurements was evaluated using the maximum head difference between paired ports; a mean difference of 0.04 ft showed excellent agreement between measurements.

The most dramatic changes in head occurred near sediment layers. For example, layers of sediment in borehole MIDDLE 2051 coincided with a -6.5 ft head loss and in borehole USGS 133, a 33 ft sediment layer resulted in a -4.6 ft head loss. In some boreholes, however, head was insensitive to sediment layers making it difficult to determine head changes based on core and geophysical information alone. Vertical hydraulic gradients were defined for the major inflections in the head profiles and were as much as -2.2 ft ft^{-1}. Gradients were generally downward in boreholes USGS 133, USGS 134, and MIDDLE 2050A, zero in boreholes USGS 103 and USGS 132, and exhibited a reversal in direction in borehole MIDDLE 2051.

Water temperature in all six boreholes ranged from 10.2 °C in borehole USGS 132 to 16.3 °C in borehole MIDDLE 2050A. Boreholes USGS 103 and USGS 132 were established near the southern boundary of the INL in an area of concentrated volcanic vents and fissures, and show water temperature decreasing with depth. All other boreholes show water temperature increasing with depth.

Vertical head and temperature profiles were unique to each borehole and characteristic of the extreme heterogeneity and anisotropy of the eastern Snake River Plain aquifer. Vertical hydraulic gradients in each borehole remained relatively constant over time with minimum Pearson correlation coefficients between profiles ranging from 0.72 at borehole USGS 103 to 1.00 at boreholes USGS 133 and MIDDLE 2051. A comparison among boreholes of the mean head over time suggests a moderately positive correlation, which indicates regional fluctuations in the water table due to seasonal changes in recharge conditions.

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Appendix A. Data Used to Calculate Pressure Probe Transducer Depths at Measurement Port Couplings, Boreholes USGS 103, USGS 132, USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051, Idaho National Laboratory, Idaho, 2007–08

Table A1. Data used to calculate pressure probe transducer depths at measurement port couplings, boreholes USGS 103, USGS 132, USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051, Idaho National Laboratory, Idaho, 2007–08.

[**Local name:** Local well identifier used in this study. **Port No.:** Identifier used to locate port couplings. **Water depth:** Depth to water inside the multiport casing. **Fluid pressure:** Measured inside the multiport casing. **Pressure transducer depth:** Depth to the pressure transducer sensor in the measurement port coupling. **Abbreviations:** ft bls, foot below land surface; psia, pound per square inch absolute; °C, degrees Celsius; NA, data not available]

Local name	Port No.	Water depth (ft bls)	Atmospheric pressure (psia)	Water temperature (°C)	Fluid pressure (psia)	Pressure transducer depth (ft bls)
USGS 103	1	585.50	12.321	12.6	304.01	1,258.7
	2	585.56	12.322	12.6	297.70	1,244.2
	3	585.67	12.322	12.5	282.99	1,210.3
	4	585.77	12.322	12.5	272.24	1,185.6
	5	585.97	12.321	12.4	242.17	1,116.4
	6	586.01	12.320	12.4	235.86	1,101.9
	7	586.07	12.320	12.5	229.57	1,087.5
	8	586.13	12.319	12.4	219.57	1,064.4
	9	586.18	12.319	12.4	211.87	1,046.7
	10	586.27	12.319	12.4	199.28	1,017.8
	11	586.36	12.319	12.5	188.78	993.6
	12	586.45	12.319	12.5	173.88	959.3
	13	586.49	12.318	12.5	169.68	949.7
	14	586.53	12.319	12.6	158.47	923.8
	15	586.61	12.319	12.6	152.17	909.4
	16	586.68	12.320	12.6	144.97	892.8
	17	586.82	12.321	12.7	132.36	863.9
	18	586.86	12.321	12.7	120.44	836.4
	19	586.96	12.321	12.8	105.73	802.5
	20	587.07	12.320	12.8	90.80	768.2
	21	587.27	12.322	13.0	59.23	695.5
	22	587.29	12.323	13.1	52.93	681.0
	23	587.35	12.324	13.2	48.51	670.9
USGS 132	1	618.84	12.253	10.7	252.71	1,173.7
	2	618.88	12.252	10.6	243.99	1,153.6
	3	618.90	12.252	10.7	240.43	1,145.4
	4	618.95	12.252	10.7	236.16	1,135.6
	5	619.25	12.250	11.2	197.77	1,047.3
	6	619.36	12.248	11.7	182.51	1,012.3
	7	619.39	12.248	12.0	170.94	985.6
	8	619.44	12.247	12.1	157.41	954.4
	9	619.48	12.247	12.2	150.99	939.7
	10	619.56	12.246	12.3	142.14	919.3
	11	619.60	12.245	12.3	139.09	912.3
	12	619.71	12.245	12.4	124.14	878.0
	13	619.75	12.245	12.4	119.86	868.1
	14	619.83	12.244	12.5	102.44	828.0
	15	619.86	12.244	12.5	95.83	812.8
	16	619.90	12.243	12.5	91.54	802.9
	17	619.92	12.242	12.4	86.55	791.4
	18	619.98	12.242	12.4	75.54	766.1
	19	620.11	12.241	12.3	58.94	727.9
	20	620.32	12.240	11.9	35.39	673.7
	21	620.33	12.240	11.7	31.11	663.9
	22	620.40	12.240	11.6	20.10	638.5
	23	620.41	12.240	11.5	14.15	624.8

Table A1. Data used to calculate pressure probe transducer depths at measurement port couplings, boreholes USGS 103, USGS 132, USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051, Idaho National Laboratory, Idaho, 2007–08.—Continued.

[**Local name:** Local well identifier used in this study. **Port No.:** Identifier used to locate port couplings. **Water depth:** Depth to water inside the multiport casing. **Fluid pressure:** Measured inside the multiport casing. **Pressure transducer depth:** Depth to the pressure transducer sensor in the measurement port coupling. **Abbreviations:** ft bls, foot below land surface; psia, pound per square inch absolute; °C, degrees Celsius; NA, data not available]

Local name	Port No.	Water depth (ft bls)	Atmospheric pressure (psia)	Water temperature (°C)	Fluid pressure (psia)	Pressure transducer depth (ft bls)
USGS 133	1	448.34	12.326	12.2	141.38	746.2
	2	448.38	12.325	12.1	132.65	726.1
	3	448.39	12.328	12.0	128.40	716.3
	4	448.39	12.322	11.9	121.29	699.9
	5	448.39	12.323	11.9	115.62	686.8
	6	448.50	12.328	11.6	86.43	619.5
	7	448.53	12.331	11.4	75.77	594.9
	8	448.55	12.333	11.4	65.09	570.3
	9	448.57	12.333	11.3	59.20	556.7
	10	448.57	12.332	11.3	52.10	540.3
	11	448.68	12.332	11.1	27.86	484.5
	12	448.69	12.333	11.1	21.47	469.8
	13	NA	NA	NA	NA	[1] 449.7
USGS 134	1	519.86	12.313	14.9	169.24	882.2
	2	519.90	12.313	14.8	164.88	872.1
	3	NA	NA	NA	NA	[1] 856.6
	4	520.07	12.312	14.6	153.99	847.1
	5	520.16	12.311	14.5	147.45	832.1
	6	520.21	12.311	14.4	143.09	822.1
	7	520.31	12.311	14.3	136.56	807.1
	8	520.47	12.311	14.2	126.10	783.1
	9	520.69	12.310	14.0	110.83	748.1
	10	520.86	12.310	13.8	100.36	724.1
	11	520.97	12.310	13.6	92.94	707.1
	12	521.07	12.310	13.5	86.39	692.1
	13	521.23	12.310	13.4	75.04	666.0
	14	521.30	12.310	13.3	70.68	656.0
	15	521.40	12.310	13.3	66.31	646.0
	16	521.41	12.310	13.2	63.70	640.0
	17	521.63	12.309	13.1	48.85	606.0
	18	521.71	12.308	13.0	43.60	593.9
	19	518.13	12.307	12.9	38.68	579.0
	20	518.29	12.308	12.8	28.19	555.0
MIDDLE 2050A	1	478.81	12.304	16.3	354.39	1,268.7
	2	478.94	12.303	15.8	338.01	1,231.0
	3	479.09	12.300	15.2	316.32	1,181.0
	4	479.38	12.300	14.4	273.60	1,082.6
	5	479.51	12.299	14.1	257.22	1,044.9
	6	479.66	12.297	14.1	237.70	1,000.0
	7	480.13	12.297	13.2	170.11	844.4
	8	480.23	12.295	12.9	155.88	811.6
	9	480.31	12.295	12.7	147.02	791.3
	10	480.54	12.293	12.1	116.40	720.8
	11	480.56	12.292	11.9	110.69	707.6
	12	480.71	12.292	11.5	83.30	644.6
	13	480.82	12.291	11.4	74.74	625.0
	14	481.06	12.290	11.2	39.08	543.0
	15	481.13	12.289	11.1	28.05	518.0

Table A1. Data used to calculate pressure probe transducer depths at measurement port couplings, boreholes USGS 103, USGS 132, USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051, Idaho National Laboratory, Idaho, 2007–08.—Continued.

[**Local name:** Local well identifier used in this study. **Port No.:** Identifier used to locate port couplings. **Water depth:** Depth to water inside the multiport casing. **Fluid pressure:** Measured inside the multiport casing. **Pressure transducer depth:** Depth to the pressure transducer sensor in the measurement port coupling. **Abbreviations:** ft bls, foot below land surface; psia, pound per square inch absolute; °C, degrees Celsius; NA, data not available]

Local name	Port No.	Water depth (ft bls)	Atmospheric pressure (psia)	Water temperature (°C)	Fluid pressure (psia)	Pressure transducer depth (ft bls)
MIDDLE 2051	1	594.30	12.294	15.0	249.35	1,142.0
	2	594.32	12.292	15.0	245.10	1,132.0
	3	594.41	12.292	15.0	227.74	1,092.0
	4	594.63	12.290	14.8	189.38	1,003.0
	5	594.95	12.286	13.6	136.05	881.0
	6	595.09	12.286	13.4	112.98	828.0
	7	595.17	12.287	13.4	98.05	793.0
	8	595.19	12.284	13.3	90.22	775.0
	9	595.21	12.284	13.1	79.22	750.0
	10	595.47	12.279	11.5	35.02	648.0
	11	595.53	12.280	10.7	20.05	613.0
	12	595.55	12.279	10.5	15.75	604.0

[1] Estimated depth of pressure transducer sensor was based on depth measurements at adjacent port couplings and nominal casing lengths specified in the multilevel installation log.

Appendix B. Field Sheet Used for Data Collection at Multilevel Monitoring Boreholes, Idaho National Laboratory, Idaho

United States Department of the Interior
U.S. Geological Survey

Revision: 8/4/2010

Multilevel Monitoring System
Field Data and Calculation Sheet

Local name: ____________
BC altitude [Z]: ____________ ft amsl
Stick-up: ____________ ft
Probe number: ____________
Probe range: ____________ psia
Barometer number: ____________
Well casing type: ____________

Site number: ____________
Date (m/d/y): ____________
Start/Stop time: ____________
Weather conditions: ____________
Operators initials: ____________
Comments: ____________

Ambient Readings

Fluid pressure (probe)
Start: ________ psia Finish: ________ psia
Water temperature (probe)
Start: ________ °C Finish: ________ °C
Atmospheric pressure (barometer)
Start: ________ psia Finish: ________ psia

Port number	Depth to top of port coupling from log (0.1 ft bls)	Depth to pressure transducer sensor [D] (0.1 ft bls)	Atmospheric pressure [P_{Atm}] (0.001 psia)	Fluid pressure readings (0.01 psia)			Probe temperature [T] (0.1 °C)	Time H:M:S (h:m)	Pressure head outside casing [Ψ_2] (0.01 ft)	Hydraulic head [H] (0.1 ft amsl)	Comments
				Inside casing [P_1]	Outside casing [P_2]	Inside casing [P_1]					
											Repeat measurement
											Repeat measurement

Notes:
BC: brass cap at land surface
Stick-up: distance from BC to the top of well casing
psia: pounds per square inch absolute
°C: degree Celcius
ft bls: feet below land surface or BC
ft amsl: feet above mean sea level

$\Psi_2 = ((P_2 - P_{Atm}) / \gamma_w) * 144$

$H = Z - D + \Psi_2$

$\gamma_w = 62.42796 * (1 - (((T + 288.9414) / (508929.2 * (T + 68.12963))) * (T - 3.9863)^2))$

Appendix C. Port Measurement Data Pre- and Post-Inflation of Packer Bladders at Borehole USGS 133, Idaho National Laboratory, Idaho

Table C1. Port measurement data pre- and post-inflation of packer bladders at borehole USGS 133, Idaho National Laboratory, Idaho.

[**Port No:** Identifier used to locate port couplings. **Atmospheric pressure:** Measured once at land surface prior to profiling using the pressure probe transducer and was assumed to be constant during the measurement period. **Hydraulic head:** Based on the National Geodetic Vertical Datum of 1929. **Abbreviations:** psia, pound per square inch absolute; °C, degrees Celsius; ft, foot]

Port No.	Pre-inflation (08-16-2007)				Post-inflation (08-17-2007)			
	Atmospheric pressure (psia)	Water temperature (°C)	Fluid pressure (psia)	Hydraulic head (ft)	Atmospheric pressure (psia)	Water temperature (°C)	Fluid pressure (psia)	Hydraulic head (ft)
1	12.200	15.6	148.40	4,458.4	12.185	11.9	148.14	4,457.7
2	12.200	13.7	139.69	4,458.3	12.185	11.9	139.42	4,457.7
3	12.200	13.0	135.41	4,458.2	12.185	11.7	135.12	4,457.6
4	12.200	12.7	128.33	4,458.3	12.185	11.7	128.07	4,457.7
5	12.200	13.0	122.66	4,458.3	12.185	11.6	122.41	4,457.7
6	12.200	13.5	93.51	4,458.3	12.185	11.5	95.31	4,462.4
7	12.200	14.3	82.84	4,458.3	12.185	11.4	85.00	4,463.2
8	12.200	14.9	72.17	4,458.3	12.185	11.3	74.75	4,464.2
9	12.200	15.1	66.28	4,458.3	12.185	11.2	68.87	4,464.2
10	12.200	15.4	59.16	4,458.2	12.185	11.1	61.77	4,464.2
11	12.200	15.6	34.96	4,458.2	12.185	11.1	37.58	4,464.2
12	12.200	15.4	28.54	4,458.1	12.185	11.1	31.16	4,464.1
13	12.200	15.3	19.76	4,457.9	12.185	11.1	22.44	4,464.1

Appendix D. Calibration Results for Fluid Pressure Sensor, a Component of the Sampling Probe Used in Boreholes USGS 103, USGS 132, USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051, Idaho National Laboratory, Idaho, 2006–09

Table D1. Calibration results for fluid pressure sensor, a component of the sampling probe used in boreholes USGS 103, USGS 132, USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051, Idaho National Laboratory, Idaho, 2006–09.

[**Post-calibration:** Calibration performed after sensor adjustment by the probe manufacturer. **Pre-calibration:** Calibration performed prior to sensor adjustment. **Ref press:** Reference pressure measured at a specified accuracy of ±0.1 pounds per square inch. **Error:** The difference between the monitored and referenced pressure. **Abbreviations:** °C, degrees Celsius; psia, pound per square inch absolute; psi, pound per square inch]

Post-calibration, 12-21-2006				Pre-calibration, 10-20-2007			
Temperature 10.2 °C		Temperature 20.0 °C		Temperature 10.1 °C		Temperature 20.0 °C	
Ref press (psia)	Error (psi)	Ref press (psia)	Error (psi)	Ref press (psia)	Error (psi)	Ref press (psia)	Error (psi)
14.549	0.065	14.467	0.065	14.509	0.138	14.462	0.139
50.048	0.014	50.545	-0.006	50.131	0.062	49.099	0.063
98.780	-0.066	99.605	-0.065	99.556	0.000	99.114	-0.006
148.742	-0.065	149.865	-0.077	149.024	-0.015	149.735	-0.014
198.752	-0.042	198.518	-0.059	198.822	0.012	198.606	-0.004
248.486	0.002	249.043	0.012	248.278	0.058	248.922	0.062
298.526	0.037	298.708	0.029	298.301	0.093	298.394	0.060
348.446	0.089	348.087	0.063	348.652	0.126	348.026	0.093
397.847	0.080	398.382	0.077	398.165	0.124	398.289	0.010
448.215	0.017	447.725	0.009	447.622	0.077	447.902	0.036
497.783	-0.098	497.731	-0.117	498.222	-0.072	498.119	-0.064
449.717	0.029	449.890	0.020	449.274	0.068	449.624	0.045
400.437	0.086	400.193	0.073	400.128	0.127	400.486	0.114
350.776	0.102	349.851	0.057	350.365	0.156	349.999	0.125
297.896	0.048	300.668	0.037	299.481	0.105	297.295	0.097
248.894	0.033	251.559	0.016	251.186	0.086	248.794	0.082
199.992	-0.037	198.363	-0.037	196.700	0.021	199.590	0.022
149.664	-0.070	149.297	-0.072	150.373	-0.011	148.754	-0.019
100.297	-0.071	100.983	-0.058	100.002	-0.003	100.592	0.014
50.739	0.004	51.000	0.006	51.251	0.078	51.034	0.077
14.571	0.072	14.487	0.069	14.529	0.143	14.478	0.140

Post-calibration, 10-20-2007				Pre-calibration, 10-22-2008			
Temperature 10.1 °C		Temperature 20.0 °C		Temperature 10.1 °C		Temperature 20.0 °C	
Ref press (psia)	Error (psi)	Ref press (psia)	Error (psi)	Ref press (psia)	Error (psi)	Ref press (psia)	Error (psi)
14.509	0.074	14.462	0.073	14.749	-0.045	14.783	-0.036
50.131	0.000	49.099	0.000	51.140	-0.157	51.289	-0.164
99.556	-0.059	99.114	-0.066	98.814	-0.239	99.267	-0.258
149.024	-0.072	149.735	-0.071	148.922	-0.273	149.614	-0.260
198.822	-0.043	198.606	-0.057	198.782	-0.239	197.975	-0.228
248.278	0.005	248.922	0.011	249.159	-0.147	248.398	-0.150
298.301	0.042	298.394	0.011	297.607	-0.106	298.694	-0.120
348.652	0.077	348.026	0.046	348.147	-0.055	347.625	-0.081
398.165	0.077	398.289	0.056	398.171	-0.052	397.485	-0.078
447.622	0.032	447.902	-0.009	447.300	-0.097	446.993	-0.132

Table D1. Calibration results for fluid pressure sensor, a component of the sampling probe used in boreholes USGS 103, USGS 132, USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051, Idaho National Laboratory, Idaho, 2006–09.—Continued

[**Post-calibration:** Calibration performed after sensor adjustment by the probe manufacturer. **Pre-calibration:** Calibration performed prior to sensor adjustment. **Ref press:** Reference pressure measured at a specified accuracy of ±0.1 pounds per square inch. **Error:** The difference between the monitored and referenced pressure. **Abbreviations:** °C, degrees Celsius; psia, pound per square inch absolute; psi, pound per square inch]

Post-calibration, 10-20-2007—Continued				Pre-calibration, 10-22-2008—Continued			
Temperature 10.1 °C		Temperature 20.0 °C		Temperature 10.1 °C		Temperature 20.0 °C	
Ref press (psia)	Error (psi)	Ref press (psia)	Error (psi)	Ref press (psia)	Error (psi)	Ref press (psia)	Error (psi)
498.222	-0.115	498.119	-0.108	496.764	-0.265	496.870	-0.273
449.274	0.023	449.624	0.001	449.328	-0.104	449.926	-0.122
400.128	0.080	400.486	0.068	400.218	-0.053	400.569	-0.057
350.365	0.107	349.999	0.078	350.535	-0.049	350.628	-0.073
299.481	0.054	297.295	0.048	300.538	-0.092	300.826	-0.118
251.186	0.033	248.794	0.031	248.155	-0.162	247.778	-0.165
196.700	-0.034	199.590	-0.032	201.072	-0.222	201.244	-0.213
150.373	-0.068	148.754	-0.076	147.858	-0.252	147.575	-0.248
100.002	-0.063	100.592	-0.046	99.856	-0.244	100.144	-0.252
51.251	0.016	51.034	0.014	49.686	-0.166	50.011	-0.157
14.529	0.079	14.478	0.074	14.739	-0.042	14.769	-0.036
Post-calibration, 10-22-2008				**Pre-calibration, 11-07-2009**			
Temperature 10.1°C		**Temperature 20.0 °C**		**Temperature 9.9°C**		**Temperature 19.7°C**	
Ref press (psia)	**Error (psi)**	**Ref press (psia)**	**Error (psi)**	**Ref press (psia)**	**Error (psi)**	**Ref press (psia)**	**Error (psi)**
14.749	0.091	14.783	0.105	14.551	0.278	14.546	0.262
51.140	-0.010	51.289	-0.013	49.453	0.190	50.512	0.173
98.814	-0.082	99.267	-0.097	98.852	0.107	98.755	0.125
148.922	-0.108	149.614	-0.092	148.236	0.110	149.257	0.096
198.782	-0.071	197.975	-0.056	198.437	0.136	198.975	0.137
249.159	0.022	248.398	0.023	247.797	0.187	248.829	0.197
297.607	0.059	298.694	0.049	298.215	0.230	297.628	0.237
348.147	0.103	347.625	0.082	347.388	0.269	347.256	0.256
398.171	0.095	397.485	0.073	397.525	0.254	397.967	0.234
447.300	0.035	446.993	0.004	447.703	0.191	447.854	0.158
496.764	-0.152	496.870	-0.156	497.802	0.007	498.088	0.020
449.328	0.028	449.926	0.014	449.314	0.186	449.097	0.160
400.218	0.093	400.569	0.094	399.624	0.245	399.614	0.235
350.535	0.109	350.628	0.089	350.388	0.283	349.389	0.243
300.538	0.074	300.826	0.050	297.850	0.232	300.526	0.222
248.155	0.007	247.778	0.008	250.545	0.208	248.072	0.193
201.072	-0.053	201.244	-0.041	199.742	0.143	198.910	0.146
147.858	-0.087	147.575	-0.080	147.998	0.107	148.573	0.106
99.856	-0.087	100.144	-0.091	99.805	0.119	100.988	0.126
49.686	-0.020	50.011	-0.007	50.836	0.171	51.532	0.174
14.738	0.095	14.766	0.105	14.561	0.258	14.552	0.253

Appendix E. Barometric Pressure, Water Temperature, Fluid Pressure, and Hydraulic Head Data from Port Measurements for Boreholes USGS 103, USGS 132, USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051, Idaho National Laboratory, Idaho, 2007–08

Table E1. Barometric pressure, water temperature, fluid pressure, and hydraulic head data from port measurements for boreholes USGS 103, USGS 132, USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051, Idaho National Laboratory, Idaho, 2007–08.

[**Port No.:** Identifier used to locate port couplings. **Hydraulic head:** Based on the National Geodetic Vertical Datum of 1929. **Abbreviations:** psia, pound per square inch absolute; °C, degrees Celsius; psi, pound per square inch; ft, foot]

USGS 103 borehole						
Port No.	10-01-2007	12-03-2007	04-03-2008	06-16-2008	08-18-2008	12-03-2008
	Atmospheric pressure (psia) corresponding to measurement event					
1	12.246	12.420	12.313	12.269	12.290	12.334
2	12.247	12.418	12.314	12.268	12.290	12.335
3	12.248	12.419	12.314	12.266	12.289	12.335
4	12.248	12.419	12.314	12.265	12.289	12.336
5	12.248	12.421	12.314	12.266	12.288	12.337
6	12.248	12.421	12.314	12.265	12.288	12.337
7	12.249	12.421	12.314	12.265	12.288	12.337
8	12.249	12.422	12.314	12.262	12.287	12.337
9	12.249	12.423	12.314	12.263	12.287	12.336
10	12.248	12.423	12.314	12.261	12.286	12.337
11	12.249	12.423	12.315	12.260	12.286	12.337
12	12.250	12.421	12.315	12.259	12.285	12.338
13	12.251	12.421	12.316	12.258	12.285	12.338
14	12.251	12.424	12.316	12.259	12.285	12.338
15	12.252	12.425	12.316	12.258	12.285	12.339
16	12.253	12.424	12.316	12.259	12.285	12.338
17	12.253	12.426	12.316	12.260	12.284	12.337
18	12.253	12.425	12.316	12.258	12.284	12.337
19	12.254	12.426	12.316	12.258	12.284	12.338
20	12.253	12.427	12.316	12.260	12.283	12.338
21	12.253	12.426	12.316	12.259	12.282	12.338
22	12.253	12.426	12.316	12.258	12.281	12.338
23	12.253	12.426	12.316	12.258	12.280	12.338
	Water temperature (°C) corresponding to measurement event					
1	12.2	12.5	12.5	12.6	12.5	12.6
2	12.2	12.5	12.4	12.5	12.5	12.6
3	12.2	12.5	12.4	12.5	12.5	12.5
4	12.2	12.5	12.5	12.5	12.5	12.5
5	12.2	12.4	12.4	12.4	12.4	12.5
6	12.2	12.4	12.4	12.4	12.4	12.5
7	12.2	12.4	12.4	12.4	12.4	12.5
8	12.2	12.4	12.4	12.4	12.4	12.4
9	12.2	12.4	12.4	12.4	12.4	12.5
10	12.2	12.4	12.4	12.4	12.4	12.4
11	12.2	12.4	12.4	12.5	12.4	12.5
12	12.2	12.5	12.4	12.5	12.5	12.5
13	12.3	12.5	12.5	12.5	12.5	12.5
14	12.3	12.6	12.5	12.6	12.6	12.6
15	12.4	12.6	12.6	12.6	12.6	12.6
16	12.4	12.6	12.6	12.6	12.6	12.6
17	12.4	12.6	12.6	12.6	12.6	12.6
18	12.4	12.6	12.7	12.7	12.7	12.7
19	12.5	12.7	12.7	12.7	12.7	12.7

Table E1. Barometric pressure, water temperature, fluid pressure, and hydraulic head data from port measurements for boreholes USGS 103, USGS 132, USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051, Idaho National Laboratory, Idaho, 2007–08.—Continued

USGS 103 borehole—Continued						
Port No.	10-01-2007	12-03-2007	04-03-2008	06-16-2008	08-18-2008	12-03-2008
	Atmospheric pressure (psia) corresponding to measurement event—Continued					
20	12.5	12.7	12.8	12.8	12.8	12.8
21	12.6	12.8	12.9	13.0	13.0	12.9
22	12.7	12.9	13.0	13.1	13.1	13.0
23	12.8	13.0	13.0	13.1	13.1	13.1
	Fluid pressure (psia) corresponding to measurement event					
1	303.05	303.33	303.17	303.04	302.79	303.04
2	296.76	297.06	296.89	296.75	296.49	296.76
3	282.08	282.40	282.21	NA	281.78	282.06
4	271.39	271.68	271.51	NA	271.13	271.39
5	241.39	241.69	241.52	241.38	241.12	241.38
6	235.11	235.41	235.23	235.09	234.84	235.10
7	228.84	229.13	228.95	228.81	228.56	228.83
8	218.86	219.16	218.99	218.83	218.60	218.86
9	211.20	211.49	211.32	211.17	210.93	211.19
10	198.64	198.93	198.77	198.62	198.36	198.63
11	188.17	188.47	188.30	188.14	187.90	188.17
12	173.31	173.67	173.47	173.32	173.09	173.37
13	169.12	169.42	169.27	169.10	168.85	169.12
14	157.94	158.25	158.07	157.91	157.67	157.95
15	151.72	152.04	151.84	151.69	151.45	151.72
16	144.54	144.85	144.66	144.50	144.26	144.54
17	131.98	132.29	132.10	131.93	131.69	131.96
18	120.10	120.41	120.22	120.07	119.81	120.10
19	105.42	105.74	105.56	105.39	105.14	105.42
20	90.54	90.85	90.65	90.50	90.25	90.54
21	59.07	59.38	59.17	59.02	58.84	NA
22	52.78	53.10	52.89	52.73	52.48	52.78
23	48.38	48.70	48.48	48.33	48.09	48.38
	Hydraulic head (ft) corresponding to measurement event					
1	4,419.9	4,420.1	4,420.0	4,419.8	4,419.2	4,419.7
2	4,419.8	4,420.2	4,420.0	4,419.8	4,419.1	4,419.7
3	4,419.8	4,420.2	4,420.0	[1] 4,419.7	4,419.0	4,419.6
4	4,419.8	4,420.1	4,420.0	[1] 4,419.8	4,419.2	4,419.7
5	4,419.8	4,420.1	4,420.0	4,419.8	4,419.1	4,419.6
6	4,419.8	4,420.1	4,420.0	4,419.8	4,419.1	4,419.6
7	4,419.8	4,420.1	4,419.9	4,419.7	4,419.1	4,419.6
8	4,419.8	4,420.1	4,420.0	4,419.7	4,419.1	4,419.6
9	4,419.8	4,420.1	4,420.0	4,419.8	4,419.1	4,419.6
10	4,419.8	4,420.1	4,420.0	4,419.8	4,419.1	4,419.6
11	4,419.8	4,420.1	4,420.0	4,419.7	4,419.1	4,419.6
12	4,419.8	4,420.3	4,420.0	4,419.8	4,419.2	4,419.8
13	4,419.8	4,420.1	4,420.0	4,419.7	4,419.1	4,419.6
14	4,419.8	4,420.1	4,420.0	4,419.7	4,419.1	4,419.6
15	4,419.9	4,420.3	4,420.1	4,419.8	4,419.2	4,419.7
16	4,419.9	4,420.2	4,420.0	4,419.8	4,419.2	4,419.7
17	4,419.9	4,420.2	4,420.0	4,419.8	4,419.1	4,419.6
18	4,419.9	4,420.3	4,420.1	4,419.9	4,419.2	4,419.7
19	4,419.9	4,420.2	4,420.1	4,419.8	4,419.2	4,419.7
20	4,419.9	4,420.2	4,420.0	4,419.8	4,419.2	4,419.7
21	4,419.9	4,420.2	4,420.0	4,419.8	NA	NA
22	4,419.9	4,420.3	4,420.1	4,419.8	4,419.2	4,419.8
23	4,419.9	4,420.3	4,420.0	4,419.8	4,419.2	4,419.7

Table E1. Barometric pressure, water temperature, fluid pressure, and hydraulic head data from port measurements for boreholes USGS 103, USGS 132, USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051, Idaho National Laboratory, Idaho, 2007–08.—Continued

Port No.	USGS 132 borehole							
	03-28-2007	07-30-2007	09-17-2007	12-03-2007	04-16-2008	06-16-2008	08-12-2008	12-03-2008
	Atmospheric pressure (psia) corresponding to measurement event							
1	12.175	12.257	12.211	12.406	12.278	12.283	12.303	12.321
2	12.175	12.257	12.212	12.408	12.278	12.284	12.303	12.321
3	12.175	12.257	12.212	12.409	12.277	12.283	12.303	12.321
4	12.177	12.257	12.212	12.409	12.277	12.284	12.303	12.321
5	12.181	12.257	12.213	12.409	12.278	12.283	12.302	12.321
6	12.182	12.256	12.213	12.408	12.279	12.282	12.300	12.320
7	12.182	12.257	12.213	12.408	12.279	12.282	12.300	12.319
8	12.182	12.257	12.213	12.407	12.279	12.282	12.300	12.319
9	12.182	12.257	12.213	12.407	12.279	12.281	12.301	12.319
10	12.182	12.257	12.213	12.407	12.279	12.280	12.301	12.319
11	12.184	12.256	12.213	12.406	12.279	12.279	12.300	12.318
12	12.185	12.256	12.213	12.405	12.280	12.279	12.300	12.318
13	12.186	12.256	12.213	12.405	12.281	12.279	12.301	12.318
14	12.186	12.256	12.213	12.405	12.282	12.279	12.300	12.317
15	12.187	12.256	12.212	12.404	12.282	12.279	12.300	12.318
16	12.187	12.256	12.213	12.404	12.283	12.279	12.300	12.318
17	12.187	12.256	12.213	12.404	12.284	12.278	12.300	12.317
18	12.189	12.256	12.213	12.404	12.285	12.279	12.300	12.316
19	12.190	12.256	12.213	12.404	12.285	12.279	12.300	12.316
20	12.190	12.256	12.214	12.404	12.286	12.278	12.300	12.316
21	12.192	12.256	12.214	12.404	12.287	12.278	12.300	12.316
22	12.191	12.256	12.214	12.404	12.287	12.278	12.300	12.314
23	12.192	12.255	12.214	12.404	12.288	12.277	12.300	12.315
	Water temperature (°C) corresponding to measurement event							
1	10.5	11.5	10.6	10.5	10.7	10.6	10.6	10.5
2	10.3	10.8	10.4	10.5	10.6	10.5	10.5	10.5
3	10.2	10.6	10.3	10.4	10.5	10.5	10.5	10.5
4	10.2	10.5	10.3	10.5	10.5	10.5	10.5	10.5
5	10.6	10.7	10.6	10.7	10.9	11.3	11.2	10.9
6	11.0	11.0	10.9	11.1	11.2	11.8	11.8	11.3
7	11.4	11.4	11.3	11.5	11.6	12.0	12.0	11.7
8	11.6	11.5	11.5	11.7	11.9	12.1	12.1	11.9
9	11.7	11.7	11.6	11.9	12.0	12.2	12.2	12.0
10	11.9	11.8	11.8	12.0	12.1	12.3	12.3	12.1
11	11.9	11.9	11.9	12.1	12.2	12.3	12.3	12.2
12	12.0	12.0	12.0	12.2	12.3	12.4	12.4	12.3
13	12.1	12.1	12.1	12.3	12.4	12.4	12.4	12.4
14	12.2	12.2	12.1	12.4	12.4	12.5	12.5	12.4
15	12.2	12.2	12.2	12.4	12.4	12.5	12.5	12.4
16	12.2	12.2	12.2	12.4	12.4	12.4	12.4	12.4
17	12.1	12.2	12.2	12.4	12.4	12.4	12.4	12.4
18	12.1	12.1	12.1	12.4	12.4	12.3	12.3	12.4
19	12.0	12.1	12.1	12.3	12.3	12.2	12.2	12.3
20	11.7	11.8	11.9	12.1	12.1	11.7	11.8	12.1
21	11.6	11.7	11.7	11.9	12.0	11.6	11.6	11.9
22	11.6	11.6	11.5	11.8	11.7	11.6	11.6	11.6
23	11.6	11.6	11.5	11.8	11.7	11.6	11.6	11.5

Table E1. Barometric pressure, water temperature, fluid pressure, and hydraulic head data from port measurements for boreholes USGS 103, USGS 132, USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051, Idaho National Laboratory, Idaho, 2007–08.—Continued

USGS 132 borehole—Continued								
Port No.	03-28-2007	07-30-2007	09-17-2007	12-03-2007	04-16-2008	06-16-2008	08-12-2008	12-03-2008
	Fluid pressure (psia) corresponding to measurement event							
1	257.17	256.97	256.95	257.36	257.13	257.05	256.83	257.03
2	248.47	248.27	248.25	248.65	248.43	248.33	248.13	248.32
3	244.93	244.74	244.71	245.10	244.88	244.78	244.58	244.77
4	240.67	240.48	240.44	240.84	240.62	240.52	240.31	240.52
5	202.37	202.18	202.15	202.54	202.31	202.22	201.99	202.21
6	187.16	186.97	186.94	187.32	187.11	187.00	186.79	186.99
7	175.60	175.42	175.36	175.77	175.55	175.45	175.23	175.44
8	162.11	161.94	161.88	162.28	162.07	161.97	161.74	161.96
9	155.73	155.54	155.51	155.90	155.69	155.58	155.36	155.57
10	146.87	146.71	146.65	147.05	146.85	146.73	146.52	146.72
11	143.85	143.68	143.61	144.02	143.81	143.71	143.48	143.70
12	128.93	128.76	128.71	129.11	128.90	128.79	128.56	128.77
13	124.67	124.50	124.45	124.85	124.63	124.53	124.31	124.51
14	107.30	107.12	107.07	107.47	107.26	107.15	106.93	107.14
15	100.69	100.52	100.48	100.87	100.66	100.56	100.34	100.55
16	96.44	96.26	96.20	96.62	96.40	96.29	96.08	96.28
17	91.45	91.28	91.23	91.64	91.41	91.31	91.09	91.30
18	80.47	80.30	80.25	80.65	80.43	80.33	80.11	80.32
19	63.92	63.74	63.69	64.10	63.87	63.77	63.55	63.76
20	40.41	40.24	40.16	40.59	40.37	40.27	40.04	40.26
21	36.14	35.96	35.89	36.31	36.10	36.00	35.78	35.99
22	25.14	24.97	24.87	25.32	25.10	25.00	24.78	24.97
23	19.25	19.04	18.98	19.44	19.20	19.10	18.89	19.07
	Hydraulic head (ft) corresponding to measurement event							
1	4,420.2	4,419.6	4,419.6	4,420.1	4,419.9	4,419.7	4,419.2	4,419.6
2	4,420.2	4,419.6	4,419.6	4,420.1	4,419.9	4,419.7	4,419.2	4,419.6
3	4,420.2	4,419.6	4,419.7	4,420.1	4,419.9	4,419.7	4,419.2	4,419.6
4	4,420.2	4,419.6	4,419.6	4,420.1	4,419.9	4,419.6	4,419.1	4,419.5
5	4,420.1	4,419.5	4,419.5	4,420.0	4,419.8	4,419.6	4,419.0	4,419.4
6	4,420.1	4,419.5	4,419.5	4,419.9	4,419.8	4,419.5	4,419.0	4,419.4
7	4,420.1	4,419.5	4,419.5	4,420.0	4,419.8	4,419.5	4,419.0	4,419.4
8	4,420.1	4,419.6	4,419.5	4,420.0	4,419.8	4,419.6	4,419.0	4,419.5
9	4,420.2	4,419.6	4,419.6	4,420.1	4,419.9	4,419.6	4,419.1	4,419.5
10	4,420.1	4,419.5	4,419.5	4,420.0	4,419.8	4,419.6	4,419.0	4,419.4
11	4,420.1	4,419.6	4,419.5	4,420.0	4,419.8	4,419.6	4,419.0	4,419.5
12	4,420.1	4,419.5	4,419.5	4,420.0	4,419.8	4,419.5	4,419.0	4,419.4
13	4,420.1	4,419.5	4,419.5	4,420.0	4,419.8	4,419.6	4,419.0	4,419.4
14	4,420.1	4,419.5	4,419.5	4,420.0	4,419.8	4,419.6	4,419.0	4,419.4
15	4,420.1	4,419.5	4,419.5	4,420.0	4,419.8	4,419.6	4,419.0	4,419.5
16	4,420.1	4,419.6	4,419.5	4,420.1	4,419.8	4,419.6	4,419.1	4,419.5
17	4,420.1	4,419.6	4,419.5	4,420.1	4,419.8	4,419.6	4,419.0	4,419.5
18	4,420.1	4,419.6	4,419.6	4,420.0	4,419.8	4,419.6	4,419.0	4,419.5
19	4,420.1	4,419.5	4,419.5	4,420.0	4,419.8	4,419.6	4,419.0	4,419.4
20	4,420.0	4,419.4	4,419.4	4,419.9	4,419.7	4,419.5	4,418.9	4,419.3
21	4,420.0	4,419.4	4,419.4	4,419.9	4,419.7	4,419.5	4,418.9	4,419.4
22	4,420.0	4,419.4	4,419.3	4,419.9	4,419.6	4,419.4	4,418.9	4,419.3
23	4,420.1	4,419.4	4,419.4	4,420.0	4,419.7	4,419.5	4,419.0	4,419.4

Table E1. Barometric pressure, water temperature, fluid pressure, and hydraulic head data from port measurements for boreholes USGS 103, USGS 132, USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051, Idaho National Laboratory, Idaho, 2007–08.—Continued

USGS 133 borehole						
Port No.	09-24-2007	12-04-2007	04-04-2008	06-13-2008	08-27-2008	12-02-2008
	Atmospheric pressure (psia) corresponding to measurement event					
1	12.358	12.446	12.353	12.359	12.297	12.254
2	12.358	12.445	12.352	12.359	12.297	12.254
3	12.359	12.445	12.352	12.359	12.296	12.253
4	12.359	12.447	12.352	12.360	12.294	12.253
5	12.359	12.448	12.352	12.359	12.293	12.253
6	12.360	12.447	12.351	12.356	12.293	12.253
7	12.360	12.447	12.351	12.357	12.291	12.252
8	12.360	12.448	12.350	12.356	12.292	12.252
9	12.361	12.449	12.350	12.354	12.291	12.250
10	12.361	12.449	12.350	12.351	12.291	12.251
11	12.362	12.447	12.349	12.352	12.291	12.250
12	12.362	12.448	12.349	12.351	12.291	12.250
13	12.363	12.448	12.349	12.350	12.290	12.249
	Water temperature (°C) corresponding to measurement event					
1	11.8	10.5	12.0	12.3	12.2	11.6
2	11.8	11.0	12.0	12.1	12.1	11.8
3	11.8	11.4	12.0	12.0	12.0	11.8
4	11.7	11.6	12.0	11.9	11.9	11.9
5	11.7	11.6	11.9	11.8	11.8	11.8
6	11.5	11.6	11.7	11.6	11.6	11.6
7	11.4	11.5	11.6	11.5	11.5	11.5
8	11.3	11.5	11.5	11.4	11.4	11.5
9	11.2	11.4	11.4	11.3	11.3	11.4
10	11.1	11.3	11.4	11.3	11.3	11.3
11	11.0	11.2	11.3	11.1	11.1	11.2
12	10.9	11.2	11.2	11.1	11.1	11.1
13	10.9	11.1	11.1	11.0	11.0	11.1
	Fluid pressure (psia) corresponding to measurement event					
1	148.04	148.29	148.21	148.10	147.66	147.63
2	139.32	139.57	139.50	139.37	139.00	138.92
3	134.96	135.26	135.20	135.11	134.71	134.62
4	127.96	128.19	128.13	128.01	127.65	127.54
5	122.31	122.53	122.48	122.35	121.98	121.90
6	95.19	95.32	95.29	95.19	94.91	94.73
7	84.84	84.93	84.91	84.81	84.54	84.33
8	74.58	74.65	74.62	74.54	74.30	74.06
9	68.71	68.78	68.75	68.65	68.42	68.18
10	61.59	61.66	61.62	61.54	61.32	61.07
11	37.41	37.48	37.46	37.34	37.12	36.90
12	30.97	31.05	31.08	30.95	30.70	30.48
13	22.24	22.31	22.30	22.19	21.99	21.76
	Hydraulic head (ft) corresponding to measurement event					
1	4,457.1	4,457.4	4,457.5	4,457.2	4,456.3	4,456.4
2	4,457.1	4,457.4	4,457.5	4,457.2	4,456.5	4,456.4
3	4,456.8	4,457.3	4,457.4	4,457.1	4,456.4	4,456.2

Table E1. Barometric pressure, water temperature, fluid pressure, and hydraulic head data from port measurements for boreholes USGS 103, USGS 132, USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051, Idaho National Laboratory, Idaho, 2007–08.—Continued

USGS 133 borehole—Continued						
Port No.	09-24-2007	12-04-2007	04-04-2008	06-13-2008	08-27-2008	12-02-2008
	Hydraulic head (ft) corresponding to measurement event—Continued					
4	4,457.0	4,457.4	4,457.4	4,457.1	4,456.5	4,456.3
5	4,457.1	4,457.4	4,457.5	4,457.2	4,456.5	4,456.4
6	4,461.8	4,461.9	4,462.0	4,461.8	4,461.3	4,460.9
7	4,462.5	4,462.5	4,462.6	4,462.4	4,461.9	4,461.5
8	4,463.4	4,463.4	4,463.5	4,463.3	4,462.9	4,462.5
9	4,463.4	4,463.4	4,463.5	4,463.3	4,462.9	4,462.5
10	4,463.4	4,463.3	4,463.5	4,463.3	4,462.9	4,462.4
11	4,463.4	4,463.4	4,463.6	4,463.3	4,462.9	4,462.5
12	4,463.3	4,463.3	4,463.6	4,463.3	4,462.8	4,462.4
13	4,463.2	4,463.2	4,463.4	4,463.2	4,462.8	4,462.4

USGS 134 borehole								
Port No.	03-28-2007	07-31-2007	09-10-2007	12-04-2007	04-16-2008	06-13-2008	09-03-2008	12-02-2008
	Atmospheric pressure (psia) corresponding to measurement event							
1	12.253	12.306	12.449	12.385	12.320	12.363	12.342	12.188
2	12.256	12.306	12.451	12.384	12.320	12.363	12.341	12.188
3	NA	NA	NA	NA	NA	NA	NA	NA
4	12.258	12.305	12.451	12.384	12.320	12.361	12.342	12.191
5	12.259	12.305	12.451	12.384	12.320	12.361	12.342	12.192
6	12.259	12.305	12.451	12.382	12.318	12.361	12.342	12.192
7	12.260	12.305	12.451	12.381	12.319	12.361	12.342	12.191
8	12.257	12.304	12.451	12.381	12.318	12.359	12.342	12.192
9	12.259	12.304	12.451	12.381	12.319	12.359	12.342	12.193
10	12.258	12.302	12.451	12.381	12.319	12.358	12.342	12.193
11	12.258	12.302	12.451	12.381	12.319	12.358	12.342	12.195
12	12.261	12.301	12.452	12.381	12.319	12.357	12.341	12.196
13	12.262	12.301	12.452	12.381	12.319	12.357	12.342	12.195
14	12.260	12.301	12.452	12.381	12.319	12.354	12.342	12.196
15	12.261	12.300	12.452	12.380	12.319	12.356	12.342	12.197
16	12.262	12.300	12.452	12.380	12.318	12.355	12.342	12.196
17	12.261	12.300	12.452	12.380	12.319	12.354	12.342	12.195
18	12.264	12.299	12.452	12.380	12.318	12.354	12.342	12.195
19	12.265	12.299	12.452	12.380	12.318	12.354	12.343	12.195
20	12.266	12.298	12.452	12.380	12.318	12.354	12.344	12.194
	Water temperature (°C) corresponding to measurement event							
1	14.0	16.2	14.0	14.6	14.3	14.9	14.8	14.8
2	14.4	15.3	14.2	14.7	14.6	14.8	14.8	14.8
3	NA	NA	NA	NA	NA	NA	NA	NA
4	14.3	14.5	14.3	14.6	14.6	14.6	14.6	14.7
5	14.2	14.3	14.2	14.5	14.5	14.4	14.4	14.6
6	14.1	14.2	14.1	14.5	14.4	14.3	14.3	14.5
7	14.1	14.1	14.1	14.4	14.3	14.3	14.3	14.4
8	14.0	13.9	14.0	14.3	14.2	14.1	14.1	14.3
9	13.9	13.6	13.8	14.2	14.1	13.9	13.9	14.1
10	13.6	13.5	13.6	14.0	13.9	13.7	13.7	13.9
11	13.5	13.4	13.5	13.9	13.8	13.6	13.6	13.8

Table E1. Barometric pressure, water temperature, fluid pressure, and hydraulic head data from port measurements for boreholes USGS 103, USGS 132, USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051, Idaho National Laboratory, Idaho, 2007–08.—Continued

USGS 134 borehole—Continued								
Port No.	03-28-2007	07-31-2007	09-10-2007	12-04-2007	04-16-2008	06-13-2008	09-03-2008	12-02-2008
	Water temperature (°C) corresponding to measurement event—Continued							
12	13.4	13.2	13.4	13.7	13.7	13.5	13.5	13.7
13	13.3	13.2	13.3	13.6	13.6	13.4	13.4	13.5
14	13.2	13.1	13.2	13.5	13.5	13.3	13.3	13.4
15	13.1	13.0	13.1	13.4	13.4	13.2	13.3	13.4
16	13.1	13.0	13.0	13.3	13.3	13.2	13.2	13.3
17	13.0	12.9	12.9	13.2	13.2	13.1	13.1	13.2
18	12.9	12.8	12.8	13.1	13.1	13.0	13.0	13.1
19	12.8	12.7	12.7	13.1	13.0	12.9	12.9	13.0
20	12.7	12.6	12.6	12.9	12.9	12.8	12.8	12.9
	Fluid pressure (psia) corresponding to measurement event							
1	171.60	171.35	171.36	171.43	171.37	171.26	170.98	170.80
2	167.26	167.04	167.04	167.10	167.05	166.93	166.65	166.48
3	NA	NA	NA	NA	NA	NA	NA	NA
4	156.44	156.22	156.21	156.28	156.21	156.11	155.83	155.66
5	149.94	149.74	149.72	149.78	149.72	149.61	149.34	149.19
6	145.61	145.42	145.39	145.45	145.39	145.29	145.02	144.87
7	139.11	138.92	138.89	138.95	138.89	138.79	138.53	138.37
8	128.72	128.53	128.50	128.56	128.51	128.41	128.13	127.97
9	113.54	113.36	113.32	113.38	113.32	113.22	112.95	112.80
10	103.15	102.98	102.93	102.99	102.93	102.83	102.57	102.42
11	95.76	95.62	95.57	95.62	95.56	95.47	95.21	95.08
12	89.25	89.11	89.05	89.12	89.05	88.97	88.70	88.59
13	78.37	78.22	78.15	78.21	78.17	78.04	77.81	77.71
14	73.74	73.64	73.53	73.57	73.55	73.41	73.17	73.11
15	69.39	69.30	69.21	69.23	69.20	69.10	68.87	68.76
16	66.78	66.69	66.61	66.62	66.59	66.50	66.27	66.15
17	52.06	51.99	51.90	51.87	51.85	51.78	51.59	51.46
18	46.86	46.79	46.71	46.68	46.68	46.60	46.39	46.28
19	40.31	40.26	40.16	40.14	40.14	40.04	39.87	39.76
20	30.05	30.26	30.03	30.01	30.04	29.85	29.62	29.55
	Hydraulic head (ft) corresponding to measurement event							
1	4,454.5	4,453.9	4,453.5	4,453.9	4,453.8	4,453.5	4,452.9	4,452.9
2	4,454.5	4,454.0	4,453.6	4,453.9	4,453.9	4,453.6	4,453.0	4,452.9
3	NA	NA	NA	NA	NA	NA	NA	NA
4	4,454.5	4,453.9	4,453.6	4,453.9	4,453.9	4,453.5	4,452.9	4,452.9
5	4,454.5	4,454.0	4,453.6	4,453.9	4,453.9	4,453.5	4,453.0	4,453.0
6	4,454.6	4,454.0	4,453.6	4,453.9	4,453.9	4,453.6	4,453.0	4,453.0
7	4,454.5	4,454.0	4,453.6	4,453.9	4,453.9	4,453.6	4,453.0	4,453.0
8	4,454.5	4,454.0	4,453.6	4,453.9	4,453.9	4,453.6	4,453.0	4,453.0
9	4,454.5	4,454.0	4,453.6	4,453.9	4,453.9	4,453.5	4,453.0	4,453.0
10	4,454.5	4,454.0	4,453.6	4,453.9	4,453.9	4,453.6	4,453.0	4,453.0
11	4,454.5	4,454.1	4,453.6	4,453.9	4,453.9	4,453.6	4,453.0	4,453.1
12	4,454.5	4,454.1	4,453.6	4,453.9	4,453.9	4,453.6	4,453.0	4,453.1
13	4,455.4	4,455.0	4,454.5	4,454.8	4,454.8	4,454.4	4,453.9	4,454.0
14	4,454.7	4,454.4	4,453.8	4,454.0	4,454.1	4,453.7	4,453.2	4,453.4
15	4,454.7	4,454.4	4,453.8	4,454.0	4,454.1	4,453.8	4,453.3	4,453.4

Table E1. Barometric pressure, water temperature, fluid pressure, and hydraulic head data from port measurements for boreholes USGS 103, USGS 132, USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051, Idaho National Laboratory, Idaho, 2007–08.—Continued

USGS 134 borehole—Continued								
Port No.	03-28-2007	07-31-2007	09-10-2007	12-04-2007	04-16-2008	06-13-2008	09-03-2008	12-02-2008
	Hydraulic head (ft) corresponding to measurement event—Continued							
16	4,454.7	4,454.4	4,453.8	4,454.0	4,454.1	4,453.8	4,453.3	4,453.4
17	4,454.7	4,454.5	4,453.9	4,454.0	4,454.1	4,453.9	4,453.5	4,453.5
18	4,454.8	4,454.5	4,454.0	4,454.1	4,454.2	4,454.0	4,453.5	4,453.6
19	4,454.6	4,454.4	4,453.8	4,453.9	4,454.1	4,453.7	4,453.4	4,453.5
20	4,454.9	4,455.3	4,454.5	4,454.6	4,454.8	4,454.3	4,453.8	4,453.9

MIDDLE 2050A borehole								
Port No.	03-27-2007	07-30-2007	09-19-2007	12-04-2007	04-03-2008	06-17-2008	08-25-2008	12-02-2008
	Atmospheric pressure (psia) corresponding to measurement event							
1	12.135	12.264	12.265	12.424	12.358	12.307	12.240	12.237
2	12.131	12.263	12.263	12.424	12.358	12.306	12.239	12.236
3	12.133	12.262	12.262	12.425	12.358	12.305	12.237	12.236
4	12.135	12.261	12.262	12.424	12.358	12.303	12.236	12.236
5	12.135	12.261	12.261	12.421	12.359	12.303	12.235	12.237
6	12.136	12.260	12.261	12.418	12.359	12.304	12.235	12.237
7	12.138	12.260	12.261	12.420	12.359	12.304	12.234	12.237
8	12.138	12.260	12.260	12.422	12.359	12.303	12.232	12.237
9	12.138	12.260	12.261	12.422	12.358	12.303	12.230	12.238
10	12.138	12.259	12.261	12.421	12.358	12.304	12.231	12.238
11	12.138	12.259	12.261	12.421	12.358	12.303	12.230	12.240
12	12.138	12.259	12.260	12.421	12.358	12.305	12.226	12.241
13	12.138	12.259	12.259	12.420	12.359	12.305	12.229	12.242
14	12.139	12.259	12.257	12.420	12.358	12.306	12.226	12.241
15	12.139	12.257	12.256	12.423	12.358	12.307	12.227	12.241
	Water temperature (°C) corresponding to measurement event							
1	14.3	14.3	15.5	14.7	15.0	16.2	16.3	15.8
2	14.9	14.9	15.4	15.1	15.3	15.7	15.7	15.7
3	14.7	14.7	15.0	15.1	15.2	15.0	15.1	15.3
4	14.1	14.1	14.4	14.5	14.7	14.2	14.3	14.7
5	13.9	13.9	14.0	14.2	14.4	14.0	14.1	14.4
6	13.8	13.8	13.8	14.1	14.2	14.0	14.0	14.2
7	13.2	13.2	13.3	13.7	13.7	13.0	13.0	13.6
8	13.0	13.0	13.0	13.2	13.3	12.8	12.8	13.2
9	12.7	12.7	12.7	13.0	13.1	12.6	12.6	12.9
10	12.3	12.3	12.1	12.5	12.7	12.1	12.1	12.5
11	12.0	12.0	11.9	12.3	12.0	11.9	11.9	12.2
12	11.7	11.7	11.5	11.9	11.8	11.6	11.6	11.8
13	11.5	11.5	11.3	11.6	11.6	11.4	11.4	11.6
14	11.2	11.2	11.1	11.4	11.4	11.2	11.2	11.4
15	11.1	11.1	11.0	11.3	11.3	11.1	11.1	11.3
	Fluid pressure (psia) corresponding to measurement event							
1	353.04	352.65	352.57	352.96	352.95	352.68	352.28	352.46
2	336.93	336.55	336.45	336.87	336.81	336.56	336.16	336.30
3	315.31	314.94	314.85	315.26	315.19	314.96	314.55	314.69
4	272.71	272.37	272.26	272.65	272.60	272.37	271.97	272.09

Table E1. Barometric pressure, water temperature, fluid pressure, and hydraulic head data from port measurements for boreholes USGS 103, USGS 132, USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051, Idaho National Laboratory, Idaho, 2007–08.—Continued

MIDDLE 2050A borehole—Continued								
Port No.	03-27-2007	07-30-2007	09-19-2007	12-04-2007	04-03-2008	06-17-2008	08-25-2008	12-02-2008
	Fluid pressure (psia) corresponding to measurement event—Continued							
5	256.44	256.10	256.00	256.38	256.33	256.11	255.72	255.82
6	237.00	236.66	236.55	236.93	236.87	236.64	236.27	236.36
7	169.61	169.28	169.16	169.54	169.49	169.26	168.87	168.97
8	155.42	155.11	154.99	155.36	155.32	155.09	154.72	154.79
9	146.58	146.27	146.15	146.52	146.48	146.25	145.88	145.95
10	116.06	115.74	115.62	116.00	115.94	115.72	115.35	115.42
11	110.38	110.05	109.95	110.31	110.27	110.05	109.67	109.74
12	83.18	82.96	82.84	83.10	83.11	82.87	82.58	82.52
13	74.65	74.46	74.32	74.60	74.63	74.36	74.06	74.01
14	39.12	38.89	38.77	39.02	39.06	38.80	38.52	38.46
15	28.11	27.90	27.77	28.04	28.07	27.80	27.52	27.47
	Hydraulic head (ft) corresponding to measurement event							
1	4,446.4	4,445.3	4,445.2	4,445.6	4,445.8	4,445.4	4,444.7	4,445.0
2	4,447.1	4,445.9	4,445.7	4,446.3	4,446.3	4,445.9	4,445.1	4,445.5
3	4,447.1	4,446.0	4,445.8	4,446.4	4,446.4	4,446.0	4,445.2	4,445.5
4	4,447.1	4,446.1	4,445.8	4,446.4	4,446.4	4,446.0	4,445.2	4,445.5
5	4,447.3	4,446.2	4,446.0	4,446.5	4,446.5	4,446.1	4,445.4	4,445.6
6	4,447.3	4,446.2	4,446.0	4,446.5	4,446.5	4,446.1	4,445.4	4,445.6
7	4,447.3	4,446.3	4,446.0	4,446.5	4,446.5	4,446.1	4,445.4	4,445.6
8	4,447.3	4,446.3	4,446.0	4,446.5	4,446.6	4,446.1	4,445.5	4,445.6
9	4,447.3	4,446.3	4,446.0	4,446.5	4,446.5	4,446.1	4,445.4	4,445.6
10	4,447.3	4,446.2	4,445.9	4,446.5	4,446.5	4,446.1	4,445.4	4,445.6
11	4,447.3	4,446.3	4,446.0	4,446.5	4,446.5	4,446.2	4,445.4	4,445.6
12	4,447.6	4,446.8	4,446.5	4,446.8	4,446.9	4,446.5	4,446.0	4,445.8
13	4,447.5	4,446.8	4,446.5	4,446.8	4,447.0	4,446.5	4,446.0	4,445.8
14	4,447.6	4,446.8	4,446.5	4,446.7	4,447.0	4,446.5	4,446.0	4,445.8
15	4,447.6	4,446.8	4,446.5	4,446.8	4,447.0	4,446.5	4,446.0	4,445.9

MIDDLE 2051 borehole								
Port No.	03-26-2007	07-30-2007	09-11-2007	12-03-2007	04-03-2008	06-17-2008	08-20-2008	12-03-2008
	Atmospheric pressure (psia) corresponding to measurement event							
1	12.286	12.263	12.379	12.418	12.327	12.312	12.225	12.320
2	12.286	12.263	12.379	12.419	12.328	12.313	12.225	12.320
3	12.286	12.262	12.379	12.420	12.328	12.313	12.223	12.320
4	12.285	12.261	12.379	12.420	12.328	12.312	12.224	12.320
5	12.285	12.260	12.379	12.419	12.328	12.313	12.221	12.319
6	12.285	12.259	12.379	12.418	12.328	12.312	12.221	12.318
7	12.285	12.259	12.378	12.418	12.329	12.312	12.220	12.318
8	12.285	12.258	12.378	12.418	12.329	12.312	12.218	12.318
9	12.285	12.258	12.379	12.418	12.329	12.311	12.218	12.318
10	12.285	12.257	12.379	12.420	12.329	12.312	12.216	12.317
11	12.285	12.257	12.378	12.421	12.330	12.310	12.213	12.317
12	12.285	12.257	12.379	12.422	12.330	12.310	12.215	12.317

Table E1. Barometric pressure, water temperature, fluid pressure, and hydraulic head data from port measurements for boreholes USGS 103, USGS 132, USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051, Idaho National Laboratory, Idaho, 2007–08.—Continued

MIDDLE 2051 borehole—Continued								
Port No.	03-26-2007	07-30-2007	09-11-2007	12-03-2007	04-03-2008	06-17-2008	08-20-2008	12-03-2008
	Water temperature (°C) corresponding to measurement event							
1	14.1	15.2	14.2	13.4	14.2	15.0	15.1	13.9
2	14.5	15.0	14.5	14.1	14.5	15.0	15.0	14.3
3	14.6	14.8	14.7	14.4	14.7	15.0	15.0	14.6
4	14.6	14.5	14.5	14.6	14.8	14.7	14.7	14.6
5	13.9	13.8	13.8	14.0	14.0	13.5	13.5	13.9
6	13.4	13.3	13.4	13.7	13.7	13.3	13.3	13.6
7	13.2	13.2	13.2	13.6	13.6	13.3	13.3	13.5
8	13.2	13.1	13.1	13.5	13.5	13.3	13.3	13.4
9	13.0	12.9	13.0	13.4	13.4	13.1	13.1	13.3
10	12.1	11.9	11.9	12.6	12.8	11.4	11.4	12.1
11	11.2	11.2	11.1	12.0	12.1	10.6	10.7	11.3
12	10.7	10.7	10.7	11.3	11.6	10.4	10.5	10.9
	Fluid pressure (psia) corresponding to measurement event							
1	261.21	260.93	260.97	261.14	261.09	260.92	260.66	260.79
2	256.95	256.69	256.71	256.90	256.83	256.65	256.42	256.52
3	239.63	239.37	239.39	239.56	239.52	239.35	239.08	239.20
4	201.35	201.09	201.10	201.27	201.23	201.06	200.80	200.92
5	146.71	146.48	146.48	146.66	146.60	146.47	146.20	146.31
6	123.68	123.47	123.46	123.65	123.59	123.43	123.19	123.29
7	108.77	108.55	108.56	108.74	108.66	108.52	108.29	108.37
8	100.96	100.74	100.74	100.92	100.87	100.71	100.47	100.57
9	89.99	89.76	89.77	89.94	89.87	89.75	89.49	89.60
10	45.91	45.70	45.69	45.88	45.80	45.66	45.43	45.52
11	34.03	33.82	33.76	33.82	33.73	33.55	33.33	33.25
12	30.16	29.96	29.84	29.89	29.75	29.60	29.36	29.24
	Hydraulic head (ft) corresponding to measurement event							
1	4,430.3	4,429.8	4,429.6	4,429.8	4,430.0	4,429.7	4,429.3	4,429.3
2	4,430.3	4,429.8	4,429.5	4,429.9	4,429.9	4,429.6	4,429.3	4,429.2
3	4,430.3	4,429.8	4,429.6	4,429.8	4,430.0	4,429.7	4,429.2	4,429.3
4	4,430.3	4,429.8	4,429.5	4,429.8	4,429.9	4,429.6	4,429.2	4,429.2
5	4,427.0	4,426.5	4,426.2	4,426.6	4,426.6	4,426.3	4,425.9	4,426.0
6	4,426.9	4,426.5	4,426.2	4,426.5	4,426.6	4,426.3	4,425.9	4,425.9
7	4,426.9	4,426.4	4,426.2	4,426.5	4,426.5	4,426.3	4,425.9	4,425.9
8	4,426.9	4,426.5	4,426.2	4,426.5	4,426.6	4,426.3	4,425.9	4,425.9
9	4,427.0	4,426.5	4,426.2	4,426.5	4,426.6	4,426.3	4,426.0	4,426.0
10	4,427.0	4,426.5	4,426.2	4,426.6	4,426.6	4,426.3	4,426.0	4,426.0
11	4,434.0	4,433.6	4,433.2	4,433.2	4,433.2	4,432.9	4,432.6	4,432.2
12	4,435.0	4,434.6	4,434.0	4,434.1	4,433.9	4,433.6	4,433.3	4,432.8

Appendix F. Lithology Logs for Multilevel Groundwater Monitoring Boreholes USGS 103, USGS 132, USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051, Idaho National Laboratory, Idaho, 2007–08

Table F1. Lithology logs for multilevel groundwater monitoring boreholes USGS 103, USGS 132, USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051, Idaho National Laboratory, Idaho, 2007–08.

[**Depth interval:** Depth to the top and bottom of a lithologic unit. **Unit type:** Geologic material type associated with the lithologic unit. **Abbreviations:** ft bls, foot below land surface; ft, foot; DB, dense basalt; FB, fractured basalt; S, sediment]

Lithology logs

Depth interval Top (ft bls)	Depth interval Bottom (ft bls)	Depth interval Length (ft)	Unit type
USGS 103			
647	696	49	FB
696	731	34	DB
731	741	10	FB
741	770	30	DB
770	778	8	FB
778	785	7	DB
785	792	7	FB
792	797	5	DB
797	801	4	FB
801	811	11	DB
811	820	9	FB
820	846	26	DB
846	852	6	S
852	858	6	FB
858	900	42	DB
900	915	15	FB
915	926	11	DB
926	936	11	S
936	941	4	FB
941	961	21	DB
961	1,006	44	FB
1,006	1,027	22	DB
1,027	1,034	7	S
1,034	1,041	7	FB
1,041	1,050	9	DB
1,050	1,059	9	FB
1,059	1,067	8	DB
1,067	1,092	26	FB
1,092	1,101	9	DB
1,101	1,108	7	FB
1,108	1,115	7	DB
1,115	1,123	8	FB
1,123	1,130	7	DB
1,130	1,135	5	FB
1,135	1,189	54	DB
1,189	1,197	8	FB
1,197	1,202	5	DB
1,202	1,208	7	FB
1,208	1,221	13	DB
1,221	1,230	9	FB
1,230	1,261	31	DB
1,261	1,284	23	FB
USGS 132			
600	627	27	DB
627	628	1	S
USGS 132—Continued			
628	635	7	DB
635	663	28	FB
663	675	12	DB
675	678	3	S
678	718	40	FB
718	725	7	DB
725	736	11	FB
736	738	2	S
738	788	50	FB
788	792	4	S
792	850	58	FB
850	875	25	DB
875	900	25	FB
900	908	8	DB
908	915	7	FB
915	937	22	DB
937	975	38	FB
975	989	14	DB
989	996	7	FB
996	1,003	7	DB
1,003	1,028	25	FB
1,028	1,078	50	DB
1,078	1,106	28	FB
1,106	1,116	10	DB
1,116	1,132	16	FB
1,132	1,148	16	DB
1,148	1,156	8	FB
1,156	1,166	10	DB
1,166	1,179	13	FB
1,179	1,187	8	DB
1,187	1,225	38	FB
USGS 133			
425	447	22	DB
447	473	26	FB
473	483	10	DB
483	523	40	FB
523	556	33	DB
556	576	20	FB
576	630	54	DB
630	663	33	S
663	670	7	FB
670	671	1	S
671	688	17	DB
688	694	6	FB
694	698	4	DB
USGS 133—Continued			
698	700	2	S
700	706	6	FB
706	723	17	DB
723	730	7	FB
730	743	13	DB
743	750	7	FB
750	775	25	DB
USGS 134			
550	567	17	DB
567	582	15	FB
582	592	10	DB
592	600	8	FB
600	609	9	DB
609	617	8	FB
617	619	2	S
619	626	7	FB
626	665	39	DB
665	672	7	FB
672	676	4	S
676	678	2	FB
678	693	15	DB
693	718	25	FB
718	725	7	DB
725	732	7	FB
732	733	1	S
733	739	6	FB
739	751	12	DB
751	778	27	FB
778	785	7	DB
785	797	12	FB
797	804	7	DB
804	816	12	FB
816	834	18	DB
834	836	2	S
836	842	6	FB
842	847	5	DB
847	866	19	FB
866	882	16	DB
882	900	18	FB
MIDDLE 2050A			
450	482	32	FB
482	504	22	DB
504	518	14	FB
518	543	25	DB
MIDDLE 2050A—Continued			
543	545	2	FB
545	549	4	S
549	580	31	DB
580	600	20	FB
600	657	57	DB
657	664	7	FB
664	688	24	DB
688	700	12	FB
700	742	42	DB
742	753	11	S
753	757	4	FB
757	763	6	DB
763	780	17	FB
780	794	14	DB
794	806	12	FB
806	812	6	DB
812	831	19	FB
831	858	27	DB
858	865	7	FB
865	870	5	DB
870	900	30	FB
900	906	6	DB
906	908	2	S
908	914	6	FB
914	920	6	DB
920	924	4	FB
924	937	13	DB
937	953	16	FB
953	960	7	DB
960	963	3	FB
963	985	22	DB
985	988	3	FB
988	999	11	DB
999	1,008	9	FB
1,008	1,051	43	DB
1,051	1,061	10	S
1,061	1,115	54	DB
1,115	1,119	4	S
1,119	1,150	31	FB
1,150	1,190	40	DB
1,190	1,191	1	S
1,191	1,221	30	FB
1,221	1,231	10	DB
1,231	1,251	20	FB
1,251	1,267	16	DB
1,267	1,280	13	FB
MIDDLE 2050A—Continued			
1,280	1,380	100	S
1,380	1,400	20	FB
MIDDLE 2051			
550	569	19	DB
569	603	34	FB
603	617	14	DB
617	624	7	S
624	630	6	DB
630	635	5	S
635	662	27	DB
662	673	11	FB
673	674	1	S
674	687	13	DB
687	698	11	FB
698	702	4	DB
702	704	2	S
704	711	7	FB
711	713	2	S
713	777	64	DB
777	782	5	FB
782	830	48	DB
830	847	17	FB
847	862	15	DB
862	869	7	FB
869	881	12	DB
881	889	8	FB
889	906	17	DB
906	911	5	FB
911	921	10	DB
921	930	9	FB
930	1,005	75	DB
1,005	1,006	1	FB
1,006	1,011	5	S
1,011	1,024	13	FB
1,024	1,028	4	DB
1,028	1,061	33	FB
1,061	1,064	3	DB
1,064	1,078	14	FB
1,078	1,079	1	DB
1,079	1,088	9	FB
1,088	1,095	7	DB
1,095	1,124	29	FB
1,124	1,200	76	DB

Appendix G. Vertical Hydraulic Head Gradient Data Between Adjacent Monitoring Zones for Boreholes USGS 103, USGS 132, USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051, Idaho National Laboratory, Idaho, June 2008

Table G1. Vertical hydraulic head gradient data between adjacent monitoring zones for boreholes USGS 103, USGS 132, USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051, Idaho National Laboratory, Idaho, June 2008.

[**Local name:** Local well identifier used in this study. **Zone No.:** Identifiers used to locate monitoring zones. **Port No.:** Identifiers used to locate port couplings. **Depth interval:** Depth to the bottom and top of the inflated packer separating the adjacent monitoring zones. **Hydraulic head:** Based on the National Geodetic Vertical Datum of 1929. Vertical hydraulic head gradients are calculated over the 3.0-ft thick inflated packer bladder. **Abbreviations:** ft bls, foot below land surface; ft, foot; ft ft^{-1}, foot per foot]

Local name	Zone No.	Port No.	Depth interval		Hydraulic head			
			Bottom (ft bls)	Top (ft bls)	Bottom (ft)	Top (ft)	Difference (ft)	Gradient (ft ft^{-1})
USGS 103	1, 2	1, 2	1,257.4	1,254.4	4,419.8	4,419.8	0.0	0.0
	2, 3	2 - 4	1,242.9	1,239.9	4,419.8	4,419.8	0.0	0.0
	3, 4	3 - 5	1,184.4	1,181.4	4,419.8	4,419.8	-0.0	-0.0
	4, 5	5, 6	1,115.2	1,112.2	4,419.8	4,419.8	-0.0	-0.0
	5, 6	6 - 8	1,100.6	1,097.6	4,419.8	4,419.7	0.0	0.0
	6, 7	7 - 9	1,063.2	1,060.2	4,419.7	4,419.7	-0.0	-0.0
	7, 8	9, 10	1,045.5	1,042.5	4,419.7	4,419.8	-0.0	-0.0
	8, 9	10 - 12	1,016.5	1,013.5	4,419.8	4,419.8	-0.0	-0.0
	9, 10	11 - 13	958.0	955.0	4,419.8	4,419.7	0.0	0.0
	10, 11	13, 14	948.4	945.4	4,419.7	4,419.7	-0.0	-0.0
	11, 12	14 - 16	922.6	919.6	4,419.7	4,419.8	-0.1	-0.0
	12, 13	15 - 17	891.6	888.6	4,419.8	4,419.7	0.1	0.0
	13, 14	17, 18	862.6	859.6	4,419.7	4,419.9	-0.1	-0.0
	14, 15	18 - 20	835.1	832.1	4,419.9	4,419.8	0.0	0.0
	15, 16	19 - 21	766.9	763.9	4,419.8	4,419.8	0.0	0.0
	16, 17	21 - 23	694.3	691.3	4,419.8	4,419.8	-0.0	-0.0
USGS 132	1, 2	1 - 3	1,152.3	1,149.3	4,419.7	4,419.7	0.0	0.0
	2, 3	3, 4	1,144.1	1,141.1	4,419.7	4,419.6	0.0	0.0
	3, 4	4, 5	1,134.3	1,131.3	4,419.6	4,419.6	0.1	0.0
	4, 5	5 - 7	1,046.1	1,043.1	4,419.6	4,419.5	0.0	0.0
	5, 6	6 - 8	984.3	981.3	4,419.5	4,419.6	-0.1	-0.0
	6, 7	8, 9	953.2	950.2	4,419.6	4,419.6	-0.0	-0.0
	7, 8	9 - 11	938.4	935.4	4,419.6	4,419.6	0.1	0.0
	8, 9	10 - 12	911.1	908.1	4,419.6	4,419.5	0.0	0.0
	9, 10	12, 13	876.7	873.7	4,419.5	4,419.6	-0.0	-0.0
	10, 11	13 - 15	866.8	863.8	4,419.6	4,419.6	-0.0	-0.0
	11, 12	14 - 16	811.5	808.5	4,419.6	4,419.6	-0.0	-0.0
	12, 13	16, 17	801.6	798.6	4,419.6	4,419.6	0.0	0.0
	13, 14	17 -19	790.1	787.1	4,419.6	4,419.6	0.0	0.0
	14, 15	18 - 20	726.6	723.6	4,419.6	4,419.5	0.1	0.0
	15, 16	20, 21	672.5	669.5	4,419.5	4,419.5	-0.0	-0.0
	16, 17	21 - 23	662.6	659.6	4,419.5	4,419.5	-0.0	-0.0
USGS 133	1, 2	1 - 3	724.8	721.8	4,457.2	4,457.1	0.1	0.0
	2, 3	3, 4	715.0	712.0	4,457.1	4,457.1	-0.0	-0.0
	3, 4	4, 5	698.6	695.6	4,457.1	4,457.2	-0.0	-0.0
	4, 5	5, 6	685.5	682.5	4,457.2	4,461.8	-4.6	-1.5
	5, 6	6, 7	618.2	615.2	4,461.8	4,462.4	-0.6	-0.2
	6, 7	7 - 9	593.7	590.7	4,462.4	4,463.3	-0.9	-0.3
	7, 8	8 - 10	555.5	552.5	4,463.3	4,463.3	0.0	0.0
	8, 9	10 - 11	539.1	536.1	4,463.3	4,463.3	0.0	0.0
	9, 10	11 - 13	483.2	480.2	4,463.3	4,463.4	-0.2	-0.1

Table G1. Vertical hydraulic head gradient data between adjacent monitoring zones for boreholes USGS 103, USGS 132, USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051, Idaho National Laboratory, Idaho, June 2008.—Continued

[**Local name:** Local well identifier used in this study. **Zone No.:** Identifiers used to locate monitoring zones. **Port No.:** Identifiers used to locate port couplings. **Depth interval:** Depth to the bottom and top of the inflated packer separating the adjacent monitoring zones. **Hydraulic head:** Based on the National Geodetic Vertical Datum of 1929. Vertical hydraulic head gradients are calculated over the 3.0-ft thick inflated packer bladder. **Abbreviations:** ft bls, foot below land surface; ft, foot; ft ft^{-1}, foot per foot]

Local name	Zone No.	Port No.	Depth interval		Hydraulic head			
			Bottom (ft bls)	Top (ft bls)	Bottom (ft)	Top (ft)	Difference (ft)	Gradient (ft ft^{-1})
USGS 134	1, 2	1, 2	881.0	878.0	4,453.5	4,453.6	-0.0	-0.0
	2, 3	2 - 4	871.0	868.0	4,453.6	4,453.5	0.0	0.0
	3, 4	3 - 5	846.0	843.0	4,453.5	4,453.5	0.0	0.0
	4, 5	5, 6	831.0	828.0	4,453.5	4,453.6	-0.0	-0.0
	5, 6	6 - 8	821.0	818.0	4,453.6	4,453.6	0.0	0.0
	6, 7	7 - 9	782.0	779.0	4,453.6	4,453.5	0.0	0.0
	7, 8	9, 10	747.0	744.0	4,453.5	4,453.6	-0.0	-0.0
	8, 9	10 - 12	723.0	720.0	4,453.6	4,453.6	-0.0	-0.0
	9, 10	11 - 13	690.9	687.9	4,453.6	4,454.4	-0.8	-0.3
	10, 11	13, 14	664.9	661.9	4,454.4	4,453.7	0.7	0.2
	11, 12	14, 16	654.9	651.9	4,453.7	4,453.8	-0.0	-0.0
	12, 13	15 - 17	638.9	635.9	4,453.8	4,453.9	-0.1	-0.0
	13, 14	17, 18	604.8	601.8	4,453.9	4,454.0	-0.1	-0.0
	14, 15	18 - 20	592.8	589.8	4,454.0	4,454.0	-0.1	-0.0
MIDDLE 2050A	1, 2	1, 2	1,267.5	1,264.5	4,445.4	4,445.9	-0.5	-0.2
	2, 3	2, 3	1,229.7	1,226.7	4,445.9	4,446.0	-0.0	-0.0
	3, 4	3, 4	1,179.7	1,176.7	4,446.0	4,446.0	-0.0	-0.0
	4, 5	4, 5	1,081.3	1,078.3	4,446.0	4,446.1	-0.2	-0.1
	5, 6	5, 6	1,043.6	1,040.6	4,446.1	4,446.1	0.0	0.0
	6, 7	6, 7	998.7	995.7	4,446.1	4,446.1	-0.0	-0.0
	7, 8	7, 8	843.1	840.1	4,446.1	4,446.1	-0.0	-0.0
	8, 9	8, 9	810.4	807.4	4,446.1	4,446.1	0.0	0.0
	9, 10	9, 10	790.0	787.0	4,446.1	4,446.1	0.0	0.0
	10, 11	10, 11	719.5	716.5	4,446.1	4,446.2	-0.1	-0.0
	11, 12	11, 12	706.4	703.4	4,446.2	4,446.5	-0.3	-0.1
	12, 13	12, 13	643.3	640.3	4,446.5	4,446.5	0.0	0.0
	13, 14	13, 14	623.7	620.7	4,446.5	4,446.5	0.0	0.0
	14, 15	14, 15	541.6	538.6	4,446.5	4,446.5	0.0	0.0
MIDDLE 2051	1, 2	1, 2	1,140.3	1,137.3	4,429.7	4,429.6	0.1	0.0
	2, 3	2, 3	1,130.5	1,127.5	4,429.6	4,429.7	-0.0	-0.0
	3, 4	3, 4	1,090.5	1,087.5	4,429.7	4,429.6	0.1	0.0
	4, 5	4, 5	1,002.2	999.2	4,429.6	4,426.3	3.2	1.1
	5, 6	5, 6	879.4	876.4	4,426.3	4,426.3	0.1	0.0
	6, 7	6, 7	826.2	823.2	4,426.3	4,426.3	0.0	0.0
	7, 8	7, 8	791.9	788.9	4,426.3	4,426.3	-0.0	-0.0
	8, 9	8, 9	773.8	770.8	4,426.3	4,426.3	-0.1	-0.0
	9, 10	9, 10	748.4	745.4	4,426.3	4,426.3	0.0	0.0
	10, 11	10, 11	646.7	643.7	4,426.3	4,432.9	-6.5	-2.2
	11, 12	11, 12	612.2	609.2	4,432.9	4,433.6	-0.8	-0.3

Appendix H. Quarterly Mean and Normalized Mean Hydraulic Head Values for Boreholes USGS 103, USGS 132, USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051, Idaho National Laboratory, Idaho, 2007–08

Table H1. Quarterly mean and normalized mean hydraulic head values for boreholes USGS 103, USGS 132, USGS 133, USGS 134, MIDDLE 2050A, and MIDDLE 2051, Idaho National Laboratory, Idaho, 2007–08.

[**Local name:** Local well identifier used in this study. **Mean hydraulic head:** Based on the National Geodetic Vertical Datum of 1929. **Abbreviation:** ft, foot]

Local name	Date of measurement	Hydraulic head	
		Mean (ft)	Normalized mean (ft)
USGS 103	10-01-2007	4,419.9	0.2
	12-03-2007	4,420.2	1.2
	04-03-2008	4,420.0	0.7
	06-16-2008	4,419.8	0.0
	08-18-2008	4,419.2	-1.8
	12-03-2008	4,419.7	-0.3
USGS 132	03-28-2007	4,420.1	1.4
	07-30-2007	4,419.5	-0.3
	09-17-2007	4,419.5	-0.3
	12-03-2007	4,420.0	1.1
	04-16-2008	4,419.8	0.5
	06-16-2008	4,419.6	-0.2
	08-12-2008	4,419.0	-1.8
	12-03-2008	4,419.4	-0.5
USGS 133	09-24-2007	4,460.7	0.4
	12-04-2007	4,460.9	0.7
	04-04-2008	4,461.0	1.0
	06-13-2008	4,460.7	0.4
	08-27-2008	4,460.2	-0.9
	12-02-2008	4,459.9	-1.6
USGS 134	03-28-2007	4,454.6	0.8
	07-31-2007	4,454.2	0.6
	09-10-2007	4,453.8	0.4
	12-04-2007	4,454.0	0.5
	04-16-2008	4,454.1	0.5
	06-13-2008	4,453.7	0.4
	09-03-2008	4,450.0	-1.6
	12-02-2008	4,450.0	-1.6
MIDDLE 2050A	03-27-2007	4,447.3	1.8
	07-30-2007	4,446.3	0.1
	09-19-2007	4,446.0	-0.3
	12-04-2007	4,446.5	0.4
	04-03-2008	4,446.6	0.6
	06-17-2008	4,446.1	-0.2
	08-25-2008	4,445.5	-1.3
	12-02-2008	4,445.6	-1.1
MIDDLE 2051	03-26-2007	4,429.3	1.7
	07-30-2007	4,428.9	0.5
	09-11-2007	4,428.6	-0.3
	12-03-2007	4,428.8	0.4
	04-03-2008	4,428.9	0.6
	06-17-2008	4,428.6	-0.3
	08-20-2008	4,428.2	-1.2
	12-03-2008	4,428.1	-1.4

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U.S. Geological Survey
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